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Principal Contents

A Statistical Department in Heavy Industry..*by A. W. Swan*

An Experimental Furnace for the Investigation of Open-Hearth-Furnace Combustion Problems..*by J. F. Allen, J. H. Cook, G. Fenton and A. H. Leckie*

Open-Hearth-Furnace Instrumentation..*by E. Rogers*

First Report of the Open-Hearth Instruments Sub-Committee *by F. L. Robertson*

Ore Discharging..*by G. T. Shoosmith*

Joint Discussion on Structures in Cast Irons

Joint Discussion on Segregations and Inclusions in Steels

Discussion on the Utilization of Fuel

News and Abstracts

A full list of Contents is given on the Title Page (see page 35, Advertisement Section)

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CONTENTS

VOLUME 160 **1948**

DISCUSSION AND CORRESPONDENCE ON PAPERS

Spring Meeting, 1948 : PAGE

" The Production of Nodular Graphite Structures in Cast Irons," by H. Morrogh and W. J. Williams 21

" The Carbides in Iron–Carbon–Silicon Alloys and Cast Irons," by D. Marles 21

" A Micro-Examination of Eight Steels for the Inclusions Sub-Committee," by J. H. Whiteley ... 29

" The Study of Segregations and Inclusions in Steel by Micro-Radiography," by W. Betteridge and R. S. Sharpe 29

" Some Thermodynamical Aspects of the Formation of Inclusions in Mild-Steel Weld Metal," by E. C. Rollason and E. Bishop 29

" A Comparison of Moulds of Standard Composition and of Approximately Ingot Mould Sub-Committee Composition," by W. L. Kerlie 139

" Mould-Weight/Ingot-Weight Ratio and Its Relation to Mould Consumption," by N. H. Bacon ... 139

" Ingot Surface Defects," by P. Walker 139

" Abnormal Creep in Carbon Steels," by J. Glen 143

" The Creep Properties of Molybdenum, Chromium–Molybdenum, and Molybdenum–Vanadium Steels," by J. Glen 143

" Application of Slag Control and Investigation of Basic Open-Hearth-Furnace Slags," by T. Fairley ... 366

IRON AND STEEL INSTITUTE PAPERS

PAGE

" The Work and Organization of a Statistical Department in Heavy Industry," by A. W. Swan 1

" Rapid Estimation of Slag Basicity," by W. A. Smith, J. Monaghan, and W. Hay 121

" A Note on the Varying-Turbulence Cowper Stove," by D. Petit 131

" High-Frequency Induction Hardening," by R. J. Brown 241

Historical Note No. 8—" The Northern Extension of the Wealden Iron Industry," by H. R. Schubert... 245

" High-Speed Rotor Tests of Paints for Under-Water Service," by F. Wormwell, T. J. Nurse, and H. C. K. Ison 247

" The Structure of Carbides in Alloy Steels," by H. J. Goldschmidt 345

" The Wire-Drawers' Craft as Practised in the Warrington District," by G. K. Rylands and A. E. Sykes ... 363

" A Method of Identifying Manganese–Sulphide Inclusions in Steel," by J. H. Whiteley 365

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

" An Experimental Furnace for the Investigation of Open-Hearth Furnace Combustion Problems."

Part III—" Studies with the Maerz Port and Various Modifications Thereof," by J. F. Allen, J. H. Cook, and G. Fenton 37

Part IV—" The Study of Roof Temperatures," by J. H. Cook and A. H. Leckie 46

" Open-Hearth-Furnace Instrumentation," by E. Rogers 57

" First Report of the Open-Hearth Instruments Sub-Committee," by F. L. Robertson 72

" Ingot Structures in a Series from Rimmed to Killed Steels Made from the Same Cast," by P. M. Macnair... 151

" The Effect of Shot-Peening upon the Corrosion-Fatigue of a High-Carbon Steel," by A. J. Gould and U. R. Evans 164

" Ingot Surface Defects in Structural Steels," by L. Reeve 169

" Studies in Anti-Fouling Compositions," by H. Barnes 177

" The Thermodynamics of Substances of Interest in Iron and Steel Making from 0° C. to 2400° C.," by F. D. Richardson and J. H. E. Jeffes 261

" The Influence of Smoke and Atmospheric Absorption on Optical Pyrometry in Steelworks," by J. A. Hall 271

" The Atmospheric Corrosion of Iron and Steel Wires," by J. C. Hudson 276

" A Simple Form of Accelerated Atmospheric-Corrosion Test," by R. St. J. Preston... 286

" The Influence of Teeming Times on Ingot Surface Defects," by W. E. Goodrich 295

" A Study of the Corrosion Resistance of High-Alloy Steels to an Industrial Atmosphere," by H. T. Shirley and J. E. Truman 367

" An Examination of the Thiocyanate Porosity Test for Tinplate," by J. Pearson and W. Bullough ... 376

" Resistance Strain Gauges for the Measurement of Roll Force, Torque, and Strip Tension," by J. Rankine, W. H. Bailey, and F. P. Stanton 381

" First Report of the Gases and Non-Metallics Sub-Committee," by W. W. Stevenson, G. E. Speight, R. M. Cook, and T. Rooney 388

Part I—" Introduction," by W. W. Stevenson 388

Part II—" The Determination of Oxygen in Liquid Steel by the Aluminium-Killed Bomb Method," by G. E. Speight 390

Part III—" The Determination of Hydrogen in Liquid Steel," by G. E. Speight and R. M. Cook ... 397

Part IV—" A Co-operative Examination of a Manganese–Molybdenum Steel," by T. E. Rooney ... 406

Part V—" A Co-operative Examination of a Nickel–Chromium Steel," by T. E. Rooney 410

Part VI—" A Co-operative Examination of the Distribution of Non-Metallic Inclusions in Billets from a Mild Steel Ingot," by T. E. Rooney 413

" A Vacuum Furnace for High-Temperature Microscopy," by D. G. Nickols 415

IRON AND STEEL WORKS ENGINEERING

PAGE

"Ore Discharging," by G. T. Shoosmith 75

Report of the Sixth Meeting—(Morning Session)—Discussion on "The Engineering Aspects of the Distribution and Utilization of Gaseous Fuels in Iron and Steel Works," by J. B. R. Brooke and J. S. Bryan 85

"Belt Conveyors, Bunkers, and Chutes for Iron and Steel Works," by J. Brimelow... 185

"Specialized Rolling Stock for Iron and Steel Works," by T. H. Stayman and D. R. Brown 197

Report of the Seventh Meeting—(Morning Session)—Discussion on "Electric Control Gear for Steel-Mill Auxiliaries," by R. A. West 303

Description of New Plant: "Ore-Dressing Laboratory at the United Steel Companies, Ltd." 310

Report of the Seventh Meeting—(Afternoon Session)—Discussion on "Electronic and Servo Electronic Controls and their Application to the Iron and Steel Industry," by W. G. Thompson 417

Discussion on "The Maintenance of Electrical Machinery in Iron and Steel Works," by G. S. Martin and M. Y. Harvey 425

News 95, 213, 315, 429

Translations 98, 216, 320, 434

Abstracts 99, 217, 321, 435

Book Notices 119, 238, 343, 456

New Publications 120, 240, 344, 456

ABBREVIATIONS AND SYMBOLS

Å.	Ångstrom unit(s) = 1×10^{-10} m.
A.C.	air-cooled ; alternating current
A.H.	air-hardened
amp.	ampère(s)
amp.hr.	ampère-hour(s)
approx.	approximately
at.-%	atomic per cent
at.wt.	atomic weight
atm.	atmosphere(s) (pressure)
A.W.G.	American wire-gauge
° Bé.	Baumé (degree)
b.h.p.	brake horse-power
B. & S.	Brown and Sharpe (gauge)
B.o.T.	Board of Trade
b.p.	boiling point
B.T.U.	Board of Trade unit(s)
B.Th.U.	British thermal unit(s)
B.W.G.	Birmingham wire-gauge
° C.	centigrade (degree)
cal.	calorie(-ies)
c.c.	cubic centimetre(s)
c.d.	current density
c.g.s.	centimetre-gramme-second unit(s)
cm.	centimetre(s)
coeff.	coefficient(s)
conc.	concentrated
const.	constant(s)
cu.	cubic
cwt.	hundredweight(s)
D.C.	direct current
dia.	diameter
dil.	dilute
dm.	decimetre(s)
e.m.f.	electromotive force
e.v.	electron volt(s)
° F.	Fahrenheit (degree)
ft.	foot, feet
ft.lb.	foot-pound(s)
g.	gramme(s)
gal.	gallon(s)
H.F.	high-frequency
h.p.	horse-power
h.p.hr.	horse-power-hour(s)
hr.	hour(s)
in.	inch(es)
in.lb.	inch-pound(s)
I.S.W.G.	Imperial standard wire-gauge
° K.	absolute temperature (Kelvin scale)
kg.	kilogramme(s)
kg.cal.	kilogramme-calorie(ies)
kg.m.	kilogramme-metre(s)
km.	kilometre(s)
kV.	kilovolt(s)
kVA.	kilovolt-ampère(s)
kW.	kilowatt(s)
kWh.	kilowatt-hour(s)
kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units
lb.	pound(s)

L.F.	low-frequency
M	molar (solution)
m.	metre(s)
m.amp.	milliampère(s)
max.	maximum
mg.	milligramme(s)
min.	minimum ; minute(s)
ml.	millilitre(s)
mm.	millimetre(s)
m.m.f.	magnetomotive force
m.p.	melting point
mV.	millivolt(s)
mμ	millimicron = 1×10^{-9} m. = 10 Å.
N	normal (solution)
N.T.P.	normal temperature and pressure
O.H.	open-hearth ; oil-hardened
O.Q.	oil-quenched
oz.	ounce(s)
p.d.	potential difference
*p*H	hydrogen-ion concentration
p.p.m.	parts per million
r.p.m.	revolutions per minute
sec.	second(s)
sp.gr.	specific gravity
sq.	square
S.W.G.	standard wire-gauge
T.	tempered
temp.	temperature
V.	volt(s)
VA.	volt-ampère(s)
W.	watt(s)
Wh.	watt-hour(s)
W.G.	water-gauge
W.Q.	water-quenched
wt.	weight
wt.-%	weight per cent
yd.	yard(s)
μ	micron(s) = 1×10^{-6} m.
μg	microgramme(s) = 1×10^{-6} g.
μμ	1 millionth micron = 1×10^{-12} m. = 0·01 Å.
Ω	ohm(s)
°	degree (arc or temperature)
′	minute of arc ; foot (feet)
″	second of arc ; inch(es)
$<$	less than
$>$	greater than
$\not<$	not less than
$\not>$	not greater than
$\leq$	equal to or less than
$\geq$	equal to or greater than
$\neq$	not equal to
$\equiv$	identically equal to
$\sim$	approximately equal to
$\propto$	proportional to

SIR FREDERICK MILLS, Bt.

SIR FREDERICK MILLS, Bt., was born at West Hartlepool on St. George's Day, 1865. He was educated privately and at the Durham University College of Science, Newcastle-on-Tyne, and then, from 1881 to 1886, served his apprenticeship as an engineer at Palmers' Shipbuilding and Iron Company, Ltd., Jarrow.

His first experience of the steel industry was obtained under Herbert Le Neve Foster, at Jarrow, where he remained until 1888. In that year, at the age of 23, he was appointed the first Steelworks Manager of the Stockton Malleable Works, which later became a constituent part of the South Durham Steel Company, Ltd. In 1896, he became Manager of the Glasgow Iron Company's Steel Works at Wishaw, where he remained for three years until his appointment as General Manager of the Ebbw Vale Works. He came to Ebbw Vale with a firmly established reputation as a technician and manager, and in the following years he initiated and carried out a number of schemes for the modernization and enlargement of the works. In 1911 he became Managing Director of the Company, and Chairman and Managing Director in 1919, resigning at the end of 1929.

Immediately after taking up residence at Ebbw Vale Sir Frederick began to take part in the affairs of the County of Monmouth. He was made a Justice of the Peace in 1900, becoming High Sheriff in 1912 and Deputy Lieutenant in 1917, the latter for his work as a member of the Territorial Association and for raising a special battalion during the First World War, when he held the rank of Lieut.-Colonel. He was created a Baronet in 1921, in recognition of his services to the war effort, and in recognition of the establishment of the Ebbw Vale Industrial Council.

His retirement from industry in 1929 was not the signal for withdrawal from active life, but for his entry into a new and wider sphere. In 1931 he became Member of Parliament for Leyton East and represented that constituency continuously until 1945.

When engaged in industry, Sir Frederick always took a deep interest in technical matters and was a Member of the Institution of Civil Engineers and of the Institution of Mechanical Engineers. He became a Member of The Iron and Steel Institute in 1896, was elected to the Council in 1914 and acted as President from 1925 to 1926. He was for a number of years a Member of London University Appointments Board and Chairman from 1938 to 1945. He is a Governor of the London School of Economics.

Sir Frederick Mills, Bt.

President 1925-1926

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Work and Organization of a Statistical Department in Heavy Industry

WITH PARTICULAR REFERENCE TO THE STEEL INDUSTRY

By A. W. Swan, B.A.Sc., A.M.I.Mech.E.

SYNOPSIS

The paper is divided into three parts.

Part I deals with the basic theory. It points out that the main purpose of present-day statistics is to provide the best possible information about large numbers, through the use of small numbers. The use of sampling in giving speedy notice of change in level and/or spread through the quality-control type of chart is illustrated in an example of steelworks costs. Next considered are statistical "significance" tests, used to determine whether a difference in comparative tests is real or accidental, followed by the analysis-of-variance technique used for analysing complex situations. The concluding section deals with the use of correlation–regression methods in the study of the relationships of two or more properties.

Part II gives five examples of the application of statistical techniques and the resulting benefits, set out on a common plan : Problem, preliminary work, statistical analysis, results, and benefits. These examples differ from each other in regard to the type of problem, the technical and statistical approach, and the resulting benefits. They are : Quality control in a machine shop, sampling of silica brick, factors affecting quality of Bessemer rails, effect of coke quality and other variables on blast-furnace performance, and control and inspection of hot-rolled steel bars.

Part III is concerned with staffing and organization of statistical work. It recommends that statistical analysis should be assigned to an existing section of an organization—production, research, or inspection—and that the chief requirements for the statistical investigator should be : (1) An ability to understand the point of view and difficulties of the practical men he is to help, (2) ability to size up and analyse the problem, and (3) a sound knowledge of mathematics. Suggestions are made on the organization of the work, with particular reference to the part played by higher management. The final section deals with reports, stressing that they must be essentially practical in outlook and simple in language.

WHEN faced with the statement that modern statistical methods provide important benefits, the industrial executive has certain questions and requests to put. They are :

(1) Can the underlying principles of present-day statistical techniques be explained in non-mathematical language ? If so, please do this.

(2) What are the benefits which result from the application of statistical techniques in industry ?

(3) If it is agreed that the benefits are real, what is the organization required to make the best use of statistical methods in industry ?

PART I—UNDERLYING PRINCIPLES

FOREWORD

The following section deals with the principal statistical techniques which are of industrial value, but the treatment in no case goes beyond a discussion of the main principles, with practical examples, all of which are real problems or are based upon real problems. Full treatment will be found in the books listed at the end of the paper.

The section is written in English and not in statistical jargon. The special statistical expressions are defined.

Some explanations employ elementary algebra.

THE POPULATION

Every steelmaker realizes that casts from a particular open-hearth furnace will vary somewhat in cost however carefully conditions are controlled ; and before accepting a final figure of cost he will take the cotss of a large number of casts and strike an average. Similarly, the manager of a strip-rolling plant knows that the final thickness of his steel strip is not absolutely uniform. He is interested not only in the average thickness, but also in the total variation, as

Manuscript received 22nd June, 1948.

Mr. Swan is Head of the Statistical Section of the Research and Development Department, The United Steel Companies, Ltd., Sheffield.

1–20	21–40	41–60	61–80	81–100	101–120	121–140	141–160	161–180	181–200
13	11	14	14	20	15	8	13	16	17
19	10	15	17	16	14	14	21	14	15
13	9	20	20	12	18	11	7	20	15
14	20	15	14	12	14	18	15	19	14
16	14	16	15	14	21	15	16	23	14
12	11	17	14	14	19	14	18	14	12
16	12	16	10	11	10	17	18	20	15
22	14	12	16	14	16	19	18	9	10
22	10	12	22	23	17	19	13	18	17
16	15	21	15	26	16	14	10	14	10
14	19	18	14	14	22	16	16	13	11
17	15	16	13	16	10	12	15	13	19
12	16	13	11	10	19	10	14	21	16
17	15	12	13	16	14	10	13	13	15
19	18	15	14	14	13	17	17	18	18
16	17	13	9	15	17	11	17	14	11
17	13	19	19	16	13	18	14	20	10
11	11	14	14	15	11	15	17	16	14
14	20	13	12	13	17	11	17	14	17
15	18	17	15	10	21	10	10	21	14

Fig. 1—200 costs of chipping and rejection per cast of steel in order of occurrence

if this is too great, the strip may not be usable by the maker of the finished product; razor blades, for example. He will take a number of measurements along the length of coil in order to estimate not only the average thickness, but also the variation in thickness.

In practice, therefore, it is usual in dealing with costs, thicknesses, weights, etc., to realize that they will not be uniform, and to make an estimate of the average, and sometimes to make an estimate of the variability by taking the spread, *i.e.*, the difference between highest and lowest values. The basis is usually 5, 10, 20, etc., results, a sample from a much larger possible total.

The total number of values is, for the purpose of statistical analysis, called a population. Each population has its own individuality. Thus, casts of steel from one open-hearth furnace vary in cost to form a population of costs, but this is not identical with the population of costs from an adjoining furnace. Similarly, a coil of steel strip forms a population of thicknesses which is not identical with that from the next coil.

Let us examine the characteristics of a population of costs.

Figure 1 shows a series of 200 values of a finishing-cost index in shillings per ton for casts of open-hearth steel, taken in sequence. The cost index is real and is used for assessing in one figure the cost both of chipping billets and rejection, but the figures are not from any actual records.*

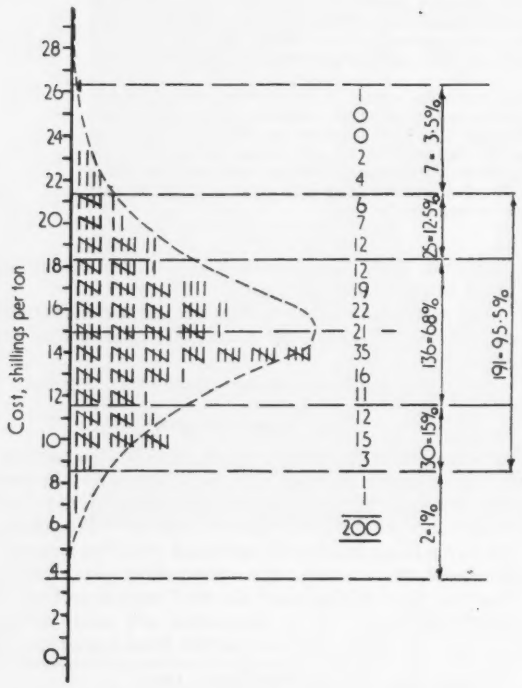


Fig. 2—The 200 costs shown in Fig. 1 rearranged as a distribution

The Distribution Curve

It is not possible by a visual examination of the figures as shown in Fig. 1 to gain an impression of general characteristics. If the values are rearranged, however, as in Fig. 2, showing in cricket-score fashion the number of times each cost has occurred, it is evident visually that the average is about 14*s.* to 15*s.*, that most of the values are clustered about the average, that the values tail off fairly rapidly upwards and downwards, and that there are only a few values at the ends of the tails, 20*s.* to 23*s.* (with one value at 26*s.*), and 7*s.* to 9*s.* The total spread is seen to be 19*s.*, from 7*s.* to 26*s.* It is possible to draw a curve round the outline of the scores, and this is known as a distribution curve.

The investigation can be carried further. If the

* The table has been constructed using the Kendall and Babington Smith "Random Numbers."

actual average, 15*s.*, is taken as the centre, we find that 136, or 68%, out of the total 200 costs come within 15*s.* ± 3*s.* = 18*s.* and 12*s.*, and that 191, or 95·5%, come within 15*s.* ± 6*s.*, *i.e.*, 21*s.* and 9*s.* Looking at this same information from the point of view of the manager who is concerned about the proportion of high costs, we see that 32, or 16%, of the individual costs have values above 18*s.*, and out of that 15·5%, 7, or 3·5%, have values above 21*s.*

In the above analysis of the distribution curve of costs it will be noticed that we have been interested both in the average value and in various aspects of the spread.

The Normal Distribution

The distribution curve in Fig. 2 is an approximation to the type of curve known as the normal distribution curve which describes a large number of processes.

The normal distribution curve is illustrated in Fig. 3. It is a smooth, single-humped, symmetrical curve with the useful property that it is completely defined when the average and the spread are known. The latter is measured by what is known as the standard deviation. The standard deviation, σ, corresponds to the root-mean-square of alternating-current electrical engineering, and, when the true average is known, it is the square root of the sum of squared deviations from average, divided by the number of values n, *i.e.*, $\sigma = \sqrt{\Sigma x^2/n}$; when the population average is an estimate made from samples $\sigma = \sqrt{\Sigma x^2/(n-1)}$. ($\Sigma x^2$ is divided by $(n-1)$ in this case to compensate for bias in the estimate introduced by the smallness of the sample.)

One of the most important properties of the normal distribution is that the proportions of the total number of values within defined limits are known in terms of the standard deviation on either side of the average. Some of these are illustrated in Fig. 3. Thus (approximately) 68% of all the values come within $\pm 1\sigma$, 95% within $\pm 2\sigma$ (2½% on either side), and 99·8% within $\pm 3\sigma$. For practical purposes the total spread of a normal distribution is thus the average $\pm 3\sigma = \bar{X} \pm 3\sigma$.

Comparison of the theoretical normal distribution curve with the curve for the 200 results in Fig. 2 is interesting from the point of view of the proportions within the limits. In the example 68·5% of the values come within $\bar{X} \pm 1\sigma$, as compared with the theoretical 68% for the normal distribution, and 96% within $\bar{X} \pm 2\sigma$, as compared with the theoretical 95%.

An important and useful advantage obtained from presenting numerical information in the form of a distribution is that it becomes possible to judge whether a single value belongs to that distribution. For example, in connection with the cost analysis set out as a distribution in Fig. 2, let us suppose that a single cost of 35*s.* occurs. We find from the graphical analysis that the highest value that has occurred is 26*s.*, and that there has been only one individual cost at 26*s.*, out of a total of 200. A cost of 35*s.* would be so unlikely that it does not seem to belong to this population and would be suspect.

Non-statistical reasoning would lead to the same result in this instance, but the difference is that statistics puts the matter on a quantitative basis.

In the case of the normal distribution a convenient rule relates the distance of a point X from the centre, $\bar{X}$, as measured in terms of the standard deviation σ, as follows :

(1) If $(X - \bar{X})/\sigma$ equals or exceeds + 3 (as X_1 in Fig. 3), it is correct to say that either the sample does not belong to the population, or a sampling accident has occurred which would occur only once in a thousand times. Practically, the chance is less than 1 in 1000 that X belongs to the population. Equally, if $(X - \bar{X})/\sigma$ equals or is less than − 3 (as X_4 in Fig. 3), the chance is less than 1 in 1000 that X belongs to the population.

If $(X - \bar{X})/\sigma$, ignoring the sign, is greater than 3, the chance is less than 1 in 500 (1 in 1000 plus 1 in 1000) that X belongs to the population.

In either case X is taken as not belonging to the population.

(2) If $(X - \bar{X})/\sigma$ equals or exceeds + 2 (as X_2 in Fig. 3), the chance is less than 1 in 40 that X belongs to the population. If $(X - \bar{X})/\sigma$ equals or is less than − 2 (as X_5 in Fig. 3), the chance is less than 1 in 40 that X belongs to the population.

If $(X - \bar{X})/\sigma$, ignoring the sign, is greater than 2, the chance is less than 1 in 20 (1 in 40 plus 1 in 40) that X belongs to the population.

In either case X probably does not belong to the population.

(3) If $(X - \bar{X})/\sigma$ is less than + 2 (as X_3 in Fig. 3), the chance is more than 1 in 40 that X belongs to the population. If $(X - \bar{X})/\sigma$ is more than − 2 (as X_4 in Fig. 3), the chance is more than 1 in 40 that X belongs to the population.

If $(X - \bar{X})/\sigma$, ignoring the sign, is less than 2, the chance is more than 1 in 20 that X belongs to the population.

In either case the position is taken as indeterminate ; X may or may not belong to the population.

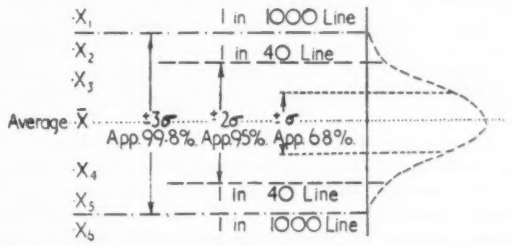


Fig. 3—Some properties of the normal distribution

Other levels of probability, 1 in 10, 1 in 20, 1 in 100, etc., associated with the appropriate values of σ, are often used, but the 1 in 40 and 1 in 1000 levels are simple and convenient to use.

To illustrate one use of the "distribution" conception let us take a typical machine-shop problem, the finishing operation on a steel sleeve having a specified external diameter of 2·000 in. ± 0·001 in. on a universal grinder which can be expected to work to ± 0·0005 in., *i.e.*, to have a spread of 0·001 in.

If the machine has been successfully set up so that the mean or average is precisely at 2·000 in., we have condition *A* in Fig. 4. As the grinding wheel wears, it will remove less material and the diameter of the sleeve will increase. Unless, however, there is some change in the general machine conditions such as the alignment of bearings, the ordinary working tolerance will not increase, and we will therefore first of all have *B*, and then as wear on the wheel continues, *C* which

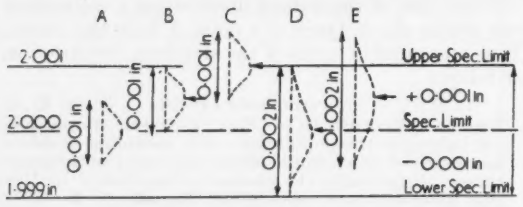


Fig. 4—Machine-shop conditions. Effects of changes in average and/or spread

will give 50% defectives, that proportion of the distribution above the specified upper limit.

It is possible that the general condition of the machine may deteriorate, causing its working tolerance to increase from $\pm 0{\cdot}0005$ in. to $\pm 0{\cdot}001$ in. With the machine set to give the correct average diameter we now have *D*, and if the grinding wheel wears as before, we will have a change of average coupled with an increased spread, giving us *E*. With *E* there will be 14% defectives.

It is evident from the above that the two types of change, that of the average and that of the spread, are separate and independent, and that it is necessary to watch changes in both.

Although the average and spread are the two main characteristics of a distribution, the industrialist is sometimes concerned more with one than the other, and he is furthermore sometimes interested not in every aspect of the spread, but only in certain particular aspects. In the case of the example of costs shown in Figs. 1 and 2, for instance, he would be interested in the average, the total spread, the proportion within certain limits, and the proportion outside those limits. In the case of rolled steel strip, the average thickness and the total spread are important, the average thickness for obvious reasons, the spread because if it is too great the strip may not be usable in certain of the machines which make the finished product as being outside their working tolerance. Ingots coming from soaking pits for rolling must neither be too hot since they will be in special danger of being " burnt," nor too cold since they will be difficult to roll and produce a larger proportion of defective billets. The main purpose, therefore, in controlling temperature at rolling is to keep the proportion within upper and lower limits as large as possible.

SAMPLING APPROACH TO THE POPULATION

So far, populations have been dealt with on the assumption that all the information about a population is available. This is seldom true even in the study of a single population, and it is practically never true in the study of more than one population.

With 100% inspection, information is available about every unit that passes through inspection, and therefore about all the production for a week, a month, a year, etc. The production for a week might be taken as a population, and in one sense it is, but the most elementary consideration shows that the " population " for a week is in fact a sample from a much larger population of many weeks. This is true of a great deal of industrial data which appears to be complete in itself, but is in fact merely a sample or specimen out of a time series.

If all the information about a population cannot be obtained, an estimate must be made through some kind of sampling.

It has long been realized that it is not possible to test or measure every grain of wheat in a granary, every lump of coal in a truck, or every drop of acid in a vat. Sampling must be adopted in such cases, and the application of present-day statistical techniques to the improvement of the sampling of actual physical things has been accepted by technical men without too much difficulty. The conception that measurements of thicknesses, weights, costs, labour turnover, etc., are also samples from populations of thicknesses, weights, costs, etc., and that they have the general characteristics of samples is much newer. It is, however, essentially reasonable.

If sampling must be done, it is only sensible that it should be done so as to give the most accurate results. The principal purpose of present-day statistics is to estimate the properties of populations through sampling within defined limits of accuracy, and in the most economical way possible. The above applies not only to the study of a single characteristic, *e.g.*, of a measurement such as steelworks costs, but to the study of relationships, for instance, the relationship between the chipping cost of billets and the temperature of ingots at rolling.

CHANGES IN POPULATION CHARACTERISTICS

One of the valuable uses of statistical methods is to provide notice of changes more promptly than is possible by any other method.

Let us take a specific case, one of steelworks costs. The figures used in the example are not taken from the records of any existing steelworks, but they correspond sufficiently closely to an actual case to have reality.

A cost department receives regularly the finishing cost per ton on each cast of steel, combining in one figure the cost of rejected billets and the cost of repair (chipping and de-seaming billets). From study of massed results the average cost is 15*s.* per ton, with the bulk of the individual costs between 23*s.* 6*d.* and 6*s.* 6*d.* and the remainder tailing off to extreme values of 27*s.* 9*d.* and 2*s.* 3*d.* In other words there is a normal distribution of costs, the average is 15*s.*; standard deviation, $\sigma = 4s.\ 3d.$, and total spread ($6\sigma = 99{\cdot}8\%$) = 25*s.* 6*d.*, population *A* in Fig. 5.

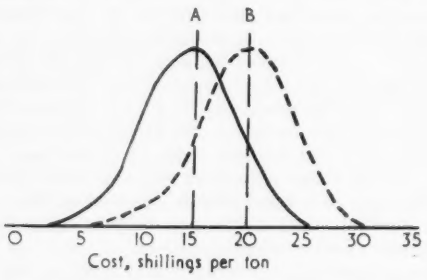


Fig. 5—A change in finishing cost per ton from 15s. average to 20s. average

How quickly can the management be warned if the average moves up from 15*s*. to, say, 20*s*., without any change in the spread, population *B* in Fig. 5 ? An increase of 5*s*. per ton is in this case 33%, a very serious matter, an event which should be known to the management as speedily as possible.

Figure 6 shows the relative efficiency in speed of warning and in the amount of information given by (1) individual results, and (2) the averages of samples of 4, 9, and 16. In all cases 20 samples (of 1, 4, 9, or 16) have been taken just before the change, *i.e.*, from the population whose average is 15*s*., and just after the change, from the population whose average is 20*s*.

The 1 in 40 limits appropriate to the " 15*s*." population are drawn in for the " individuals " and for the sample averages and standard deviations. The meaning of each limit is that so long as conditions are steady in the *A* position, not more than 1 in 40 results are to be expected above the top limit or below the bottom limit, *i.e.*, 1 in 20 outside both limits, and any larger proportion would indicate a change.

From an examination of the " individual " chart, it will be seen that between Nos. 21 and 40 are 6 results above the 1 in 40 limit, *i.e.*, 6 in 20, instead of 1 in 40, so that by result No. 40 it can be decided definitely that there has been a change upwards. Information that the change has taken place is not prompt, however ; it is difficult at this stage to estimate the extent of the change, and to tell whether the change is of the average or spread, or both.

The chart for sample averages for samples of 4 shows an improvement in promptness of notice of change and in detail of information. Five of the first ten results after the change are above the " 15*s*." 1 in 40 limit ; there is no doubt that a change has taken place. Furthermore, from results 21 to 30 it is clear that the new average is about 20*s*.

The chart for sample averages for samples of 9 and 16 is even more emphatic, and it shows more promptly when the change occurs. All the " average " results from 21 onwards are above the " 15*s*." 1 in 40 limits, and show that the upward change is of the order of 5*s*. (to a new general average of 20*s*.).

To measure spread the standard deviations have been calculated for each sample and these also are shown in Fig. 6. They all show no change in standard deviation. Hence the sample-average charts show a change in the average only (of 5*s*.), with no change in the spread.

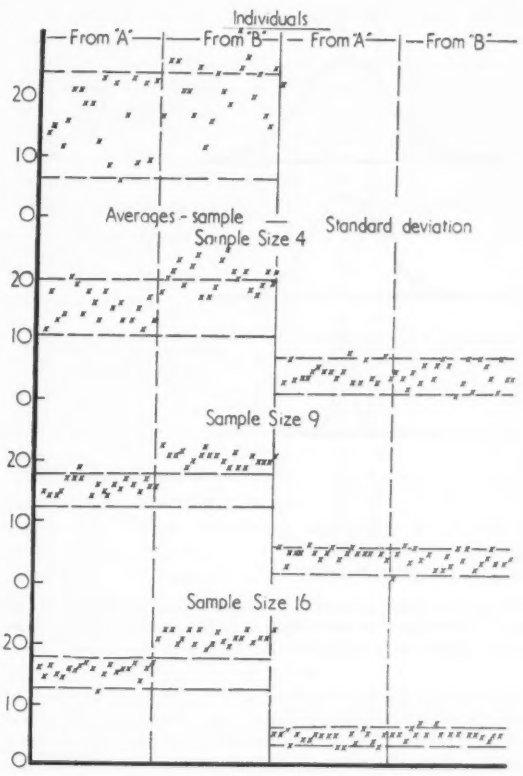


Fig. 6—Comparison in speed of notice of change of population average from 15*s*. to 20*s*. given by individuals and averages of samples 4, 9, and 16

THE QUALITY-CONTROL CHART

The charts of sample averages and standard deviations, with the appropriate 1 in 40 limits of Fig. 6 are ordinary " average, standard-deviation " quality-control charts as described in the manuals mentioned in the Bibliography. These charts have been used to date mainly for dimensions of machined parts, and in that connection are proving their worth both in regard to giving prompt notice of change, and also in giving a running commentary of machine and human conditions. In one case within the author's own personal knowledge, because of the warning given to the toolsetter by the charts before the rejection zone was reached, 500,000 brass components were machined with no rejections, after the installation of quality-control charts.

In general, as far as dimensional control is concerned, the " average " chart watches changes in the tool-setting, and the " standard-deviation " chart watches changes in machine condition. The latter property is used by at least one large aero-engine manufacturer in classifying its machine tools and assigning jobs.

For those to whom the quality-control chart is new it should be said that it is easy to put into use, since all the necessary factors can be found in the published tables, and the arithmetic is elementary, within the grasp of unskilled clerical help.

THE *t*-TEST

The quality-control chart provides a routine method of deciding whether a sample average comes from the same population as the previous data. Sometimes it is necessary to make a quick decision as to whether an average has come from a known population, and in order to do this it is necessary to know the distribution of sample averages.

Distribution of Sample Averages

From a very large population it is possible to draw many samples of, say, 5 individuals, and each sample will have its own average. Each set of sample averages,

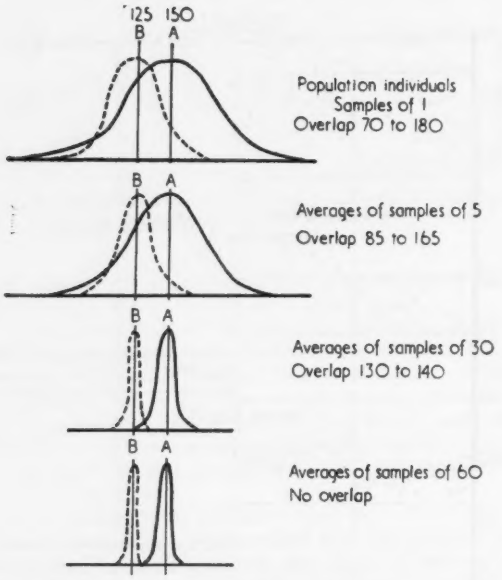


Fig. 7—Comparison of overlap for individuals and averages of samples of 5, 30, and 60, when population averages are at 125 and 150

i.e., averages for samples of, say, 5, 30, 60, etc., will form a distribution. The curves in Fig. 7 show that as the size of the sample increases, the base of the sample-average distribution narrows, and this is in accord with common sense, as at the one extreme the distribution for the averages of samples of 1 will be the same as the distribution for individuals, and at the other extreme, an infinitely large sample is the same as the population, and its average is a single point, which is the true population average.

The standard deviation of the average, which is called the standard error, is seen to be dependent upon the original distribution and also on the sample size. The formula for the standard error is $s_{\bar{x}} = \sigma/\sqrt{n}$, where σ is the estimated standard deviation of the population.

To ascertain if an average belongs to a known distribution of averages, the usual procedure for a normal distribution, described earlier in this paper, is adopted. If X_1 is the centre of the known distribution of averages, $s_{\bar{x}}$ its standard error, and X_2 is the average for comparison, then if $(X_2 - X_1)/s_{\bar{x}}$ is less than 2, the position is uncertain, if between 2 and 3, X_2 is unlikely to belong to the distribution, and if $(X_2 - X_1)/s_{\bar{x}}$ equals or exceeds 3, X_2 is taken as not belonging to the distribution.

In practice $s_{\bar{x}}$ is not known, and so it has to be estimated from the sample. If the sample is big the estimate is good and the 2σ and 3σ rule of the normal distribution can be taken.

As the sample size decreases below, say, 120, the estimate of $s_{\bar{x}}$ may be badly out, and it is not valid to compare $(X_2 - X_1)/\sigma$ with the 2σ and 3σ values of the normal case. This is because $s_{\bar{x}}$ is estimated by the formula $s_{\bar{x}} = \sigma/\sqrt{n}$, where n is the number of the sample, and the estimated value of σ is subject to error which increases as the size of sample decreases, the smaller the sample, the less likely is the estimate of σ to be correct.

Since the change from the normal distribution is progressive, it follows that no standard rule, such as the 2σ and 3σ rule for the normal distribution, can be used, and it is necessary to calculate the value of t, equal to the distance of the average under question, X, from the known centre $\bar{X}$, divided by the standard error ($t = (X - \bar{X})/s_{\bar{x}}$), and refer to the published t tables for the appropriate size of sample, the N of the table being $n - 1$, where n is the number in the sample. The tables are set out to give the same information as that provided by the 2σ and 3σ rule for the normal distribution, *i.e.*, at levels of risk such as 1 in 40, 1 in 1000, etc. It may be pointed out that where for large samples the "significant" 1 in 40 value for t is 2σ (normal distribution), it is $2{\cdot}26\sigma$ for samples of 10; $2{\cdot}37\sigma$ for samples of 8; and $3{\cdot}18\sigma$ for samples of 4.

The procedure in checking whether a sample belongs to a known population can readily be shown by an example. Suppose we have a known population which has a normal distribution, average, $X_1 = 150$; and a sample of 9 whose average, $X_2 = 180$ estimated population, standard deviation $\sigma = 15$. Does the sample belong to the known population? For sample averages $s_{\bar{x}} = s/\sqrt{n}$, so that since the sample's size is 9, $s_{\bar{x}} = 15/\sqrt{9} = 15/3 = 5$; $t = (\bar{X}_2 - \bar{X}_1)/s_{\bar{x}} = (180 - 150)/5 = 30/5 = 6$, or $\bar{X}_1 - \bar{X}_2 = 6s_{\bar{x}}$. For samples of 9, the 1 in 1000 limit is at $t = 5{\cdot}04$, so that the calculated value for t ($= 6$) is beyond the 1 in 1000 limit, and it can be assumed that the sample does not belong to the known distribution.

Quick Comparison of Two Averages

A modification of the above test arises when it is necessary to compare two sample averages with each other.

One of the problems in a steelworks is to reduce grinding cost of slabs and billets to a minimum. The ideal grinding wheel is that which combines a long life with the maximum amount of metal removed, and a cost index has been devised to measure the cost in this way. The lower the cost index, the better is the wheel from the management's point of view.

Tests on grinding wheels are lengthy and therefore expensive to carry out, so that tests must usually be confined to a relatively small number of wheels.

In the following example, figures of the same order as those on actual test have been used.

A Comparison of Costs; the *t*-Test

A comparative test was made of two sets of grinding wheels picked at random from stocks of manufacturers A and B, A being the manufacturer with whom orders have been placed, and B a competitor who might replace A. The results were as follows:

Cost Index per Wheel in Shillings

	A	B	$A - B$
	175	150	+25
	100	105	− 5
	155	125	+30
	195	100	+95
	125	145	−20
Average	150	125	25

The average difference in cost is quite substantial, 25*s.*, and it appears that the *B* wheels have a lower cost than the *A* wheels. A close examination shows, however, that there is a considerable overlap of the individual values in *A* and *B*; no less than 7 out of the 10 values come within the range 100–150, and two of the *B* values are higher than the corresponding *A* costs.

On the assumption that the samples come from different populations, the averages of which are 150 and 125 respectively, how can the fact be proved? A comparison of single individuals would be highly risky, since for instance in the second pair, $A = 100$, $B = 105$; so that in this case *A* appears to be cheaper than *B*. It may be that instead of being drawn from two separate populations of costs whose averages are separated by 25*s.*, they come from what is in effect a single population, and that *A* has been unlucky in drawing a sample of high average from that population.

There are really two interlocking problems:

(1) Can we tell from the available data whether the samples (of costs) come from distinct populations, *i.e.*, that the difference is real?

(2) If the data are insufficient to give a clear answer to (1), how much more data are required to prove that the difference is real?

Effect of Overlap

In order to solve the problems, it is necessary to estimate the extent of the overlap of the populations from which the samples are drawn, and to employ a method which will give the true averages of these populations irrespective of the overlap.

The first step is to estimate the variabilities of the two populations by calculating their standard deviations, using the formula $\sigma = \sqrt{\Sigma x^2/(n-1)}$, where σ is the standard deviation of the population estimated from the sample, Σx^2 is the sum of the squares of the deviations of the individuals in the sample from their average, and n is the number in each sample. The calculated standard deviations are $\sigma_A = 38{\cdot}1$, $\sigma_B = 22{\cdot}5$.*

When normal distributions are drawn with their averages placed at 150 and 125, and with the calculated standard deviations (*see* Fig. 7), it can be seen that the overlap for individuals is very great, and that the extent of the overlap depends on the combined variabilities of the two populations.

It follows from the previous section that as the sample size increases the base of the distribution average narrows and so overlap for particular sample sizes must decrease, and when the sample size is very big the overlap will finally disappear. It is evident from visual inspection of Fig. 7 that a comparison of averages of samples of 5 may be almost as misleading as a comparison of individuals, but that averages of samples of 30 should be reasonably safe, and that averages of samples of 60 are quite safe since overlap has disappeared.

The method described above illustrates graphically that until the sample size reaches a certain value it is impossible to tell whether a difference of sample averages is "real," *i.e.*, representing different populations, or accidental. Trial and error by this method is, however, replaced in actual practice by a method which is simple to use and accurate, but slightly more complex in theory, *viz.*, the method of "the standard error of difference."

Standard Error of Difference

Just as it is possible to have samples of individuals, *i.e.*, 175, 100, 155, etc., and 150, 105, 125, etc., so it is possible to have a sample of differences, *i.e.*, 175–150 = + 25, 100–105 = − 5, 155–125 = + 30, etc.; the sample in this case being of three differences, namely, + 25, − 5, and + 30. Such a sample of differences has its own average and its own standard deviation, called the standard error of difference, $s_{\bar{x}_A - \bar{x}_B}$. When comparing two samples of results to determine whether they come from distinct populations or not, instead of dealing with the standard error of average for each sample, the standard error of the difference of the averages is used, as it has the valuable property of representing the combined variabilities of the samples of results.

When the standard error of the difference of two averages has been obtained, the procedure in comparing the actual difference of the two samples' averages, illustrated in Fig. 8, is similar to that adopted when estimating whether a sample average comes from a known population, and the thought is the same. The difference between the sample averages, $\bar{X}_A - \bar{X}_B$, in this case equal to 25, is compared with the standard error of the difference calculated from

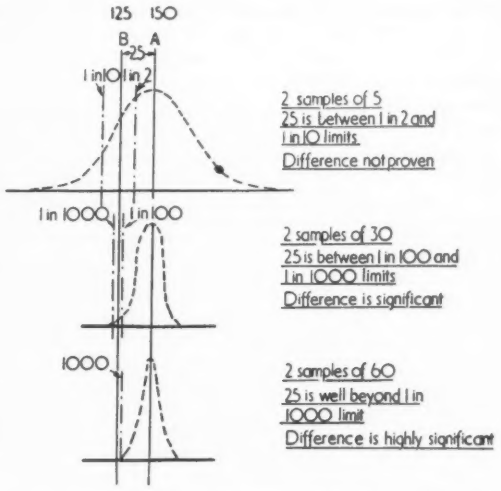


Fig. 8—An estimation of whether two samples come from two populations the averages of which are separated by 25, *e.g.*, *A* at 150, *B* at 125, using standard error of difference for pairs of samples of 5, 30, and 60

* The *t* test is valid only when there is no correlation between the individual pairs in the samples (in the case under analysis each sample is a random selection so that there is no "pairing"), and when $\sigma_A{}^2$ is not significantly greater or smaller than $\sigma_B{}^2$ (in the case under analysis $\sigma_A{}^2$ is not significantly greater than $\sigma_B{}^2$).

the two samples. Can they come from the same population, or do they come from distinct populations? If the value of t, in this case $t = (\bar{X}_A - \bar{X}_B)/s_{\bar{x}_A - \bar{x}_B}$, is sufficiently great as to place it beyond the chosen significance limits, say, 1 in 20, the difference is established ; if not, it is not proven.

In general the sign of a difference is not known at the beginning of an investigation, *i.e.*, we do not know until the comparison is made whether the wheels of manufacturer *A* cost more or less than those of manufacturer *B*. It is therefore necessary when making the significance test to consider that the point to be compared with a distribution might be outside either the right-hand or the left-hand 1 in 40 line. The risk is therefore the sum of the two risks from both tails, 1 in 40 plus 1 in 40 = 1 in 20. If, however, there is no doubt that a difference does exist, *A* (say) is greater than *B*, only one tail is in question. *A* (in this case) is either beyond the right-hand tail, or within the *B* distribution. The risk is thus halved, and the t tables can be used accordingly, *i.e.*, the 1 in 20 level becomes the 1 in 40 level, etc. This point is of particular value in the economics of testing comparisons, since data which are insufficient to give a significant answer in regard to a difference establish the sign of the difference if one exists, and the halved risk (single tail) may be used when working out the minimum size of samples to give a significant answer (on the assumption that the difference exists). The size of samples required to give any chosen level of significance is therefore much reduced, and the tests are therefore less costly.*

In the case under consideration, $\bar{X}_A - \bar{X}_B = 150 - 125 = 25$, the calculated $s_{\bar{x}_A - \bar{x}_B} = 19{\cdot}8$, so that $t = 25/19{\cdot}8 = 1{\cdot}27$, or $\bar{X}_A - \bar{X}_B = 1{\cdot}27\ s_{\bar{x}_A - \bar{x}_B}$. This value of t is such that it falls well inside the distribution (*see* Fig. 8), in fact between the 1 in 2 and 1 in 10 limits.

* The published t tables are on the basis of the higher risk, *i.e.*, " two tails."

The value 25 might thus well come from a population whose mean is zero, and the difference is not proved. It is not safe to make a decision on the costs from the two samples.

Factors Affecting Size of Sample

How large must the samples be to establish the difference ?

As stated above, t equals the average difference between the samples, divided by the standard error of difference ; $t = (\bar{X}_A - \bar{X}_B)/s_{\bar{x}_A - \bar{x}_B}$. It is known also that the standard error of difference is related to the estimated standard deviations of the populations from which two equal samples are taken, by the formula, $s_{\bar{x}_A - \bar{x}_B} = \sqrt{(\sigma_A{}^2 + \sigma_B{}^2)}/\sqrt{n}$, where n is the number in each sample. By transformation, $n = t^2(\sigma_A{}^2 + \sigma_B{}^2)/(\bar{X}_A - \bar{X}_B)^2$, and if t is the minimum value to give significance at any chosen level, say, 1 in 10, 1 in 20, etc., n is the corresponding minimum number per sample to give significance if the average difference, $\bar{X}_A - \bar{X}_B$, represents a real difference between populations.

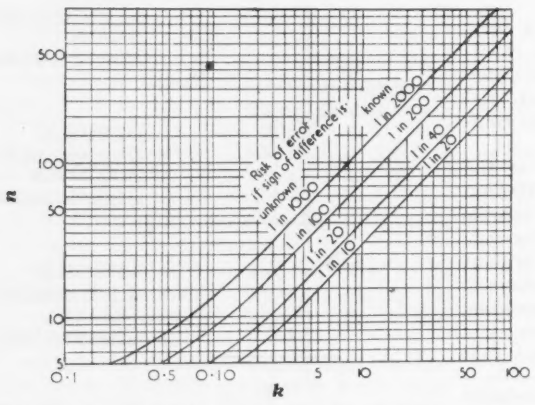
Figure 9 gives n for values of $(\sigma_A{}^2 + \sigma_B{}^2)/(\bar{X}_A - \bar{X}_B)^2$, called k for convenience, for the 1 in 10, 1 in 20, 1 in 100, and 1 in 1000 levels of significance.

For the case under analysis, $\sigma_A{}^2 + \sigma_B{}^2 = 1963$; $\bar{X}_A - \bar{X}_B = 25$, so that $k = 1963/25^2 = 3{\cdot}14$.

It will be seen from Fig. 9 that for $k = 3{\cdot}14$ we have :

Minimum n in Each Sample (nearest whole number)	Risk: Both Tails (sign of difference unknown)	Risk: Single Tail (sign of difference known)
10	1 in 10	1 in 20
14	1 in 20	1 in 40
23	1 in 100	1 in 200
38	1 in 1000	1 in 2000

Taking the 1 in 20 level as an example, it will be observed that to increase the sample size from 5 (not significant) to 14 would give a significant answer, provided that the difference of 25 is real.



n = minimum number per sample to establish a significant difference from a pair of equal randomly selected samples *A* and *B*

$k = (\sigma_A{}^2 + \sigma_B{}^2)/(\bar{X}_A - \bar{X}_B)^2$, where σ_A, σ_B are standard deviations of populations estimated from samples *A* and *B*, and $\bar{X}_A$, $\bar{X}_B$ are averages of samples *A* and *B*

***Note*—Use risk for sign of difference unknown unless strong grounds exist for believing that there is a difference—*A* is greater than or less than *B*, according to the evidence**

Fig. 9—Chart giving the minimum number of each of a pair of equal randomly selected samples to establish significance of a difference

Let us consider the general meaning of the formula for n, the minimum number per sample that will give a significant result, *i.e.*, $n = t^2\ (\sigma_A{}^2 + \sigma_B{}^2)/(\bar{X}_A - \bar{X}_B)^2$.

The terms represent the risk $1/t$, the combined variabilities within the samples $(\sigma_A{}^2 + \sigma_B{}^2)$, and the difference which is to be " picked up " $(\bar{X}_A - \bar{X}_B)^2$.

Taking t first, n varies as t^2, *i.e.*, the lower the risk, the higher is t ; greater certainty is paid for in larger samples.

Next, n varies in proportion to $\sigma_A{}^2 + \sigma_B{}^2$, the estimated combined variability of the populations from which the samples are drawn. Under ordinary conditions it is necessary to accept variability as found, with reasonable precautions to see that conditions are uniform in the tests, *i.e.*, we would check the cost of grinding wheels on the same types of steel and with the same general labour costs. Where manufacturers' products are being compared, they are presumably striving their best for uniformity, and it is of little value to ask for improvement in this direction. High variability in one or both samples is undesirable, however, as it increases the minimum n, and therefore the cost and/or trouble of the test. If the products of one manufacturer which are being compared with those of another manufacturer show a wide variation, representation can usefully be made on the subject.

Finally we come to the term $(\bar{X}_A - \bar{X}_B)^2$, the square of the difference between the sample averages, probably the most important of the three, since it largely determines whether or not it is economically worth while to secure a " significant " answer.

Two populations seldom have identical averages, but their averages may be so close together as to call for extremely large samples in order to prove that the difference exists, and the gain in information may not make up for the expense and/or trouble.

The number n varies approximately as the inverse of the square of the value $\bar{X}_A - \bar{X}_B$. For example, as shown above from Fig. 9, two samples of 14 are required to give 1 in 20 significance for a real difference between sample averages of 25 when $\sigma_A{}^2 + \sigma_B{}^2 = 1963$; *i.e.*, when $k = 1963/25^2 = 3{\cdot}14$. When $\bar{X}_A - \bar{X}_B = 20$, $k = 1963/20^2 = 4{\cdot}91$, and from Fig. 9, $n = 20$. To " pick-up " half the difference, *i.e.*, $\bar{X}_A - \bar{X}_B = 10$, instead of $\bar{X}_A - \bar{X}_B = 20$, $k = 1963/10^2 = 19{\cdot}6$ and from Fig. 9, $n = 77$, while to pick up a difference of 5, $k = 1963/5^2 = 78{\cdot}5$ and n is now 288.

It follows from the above that it is necessary in an actual comparison to decide how small a difference between population averages is worth proving. In the case of the grinding wheels, many thousand pounds per annum are spent, and an average economy of say 10*s.* per ton of product ground might be well worth while, so that the expense and trouble of comparing samples of 32 might be justified. An average saving of 5*s.*, which could be established only by using samples of 128, might be beyond the economic limit. If the difference is too small to justify the use of the full number in the samples to give significant results, the common-sense action is to use as large samples as can be employed, and employ for the special occasion a lower level of risk, even 1 in 5.

THE *F*-TEST OF DIFFERENCE IN VARIANCE

It sometimes happens that the steelworks executive is more concerned with variability than with the mean or average values.

A typical case is that of " misfit " open-hearth casts, *i.e.*, casts in which the carbon and/or manganese does not come within the specification range. Steels are specified with the carbon, manganese, etc., to come within defined ranges, *i.e.*, carbon 0·08–0·12 (often called " 8–12 "), etc. A case of 8–12 carbon steels in which the actual carbon is 7 or 13 would be called a misfit cast. It is important to know the probable expectation of misfit casts, and whether or not this varies according to the types of steel, since a misfit steel, while not necessarily scrapped, cannot be sold to the customer for whom it was originally intended, and must be sold to some other customer who calls for a steel with a higher or lower carbon, etc., as the case may be.

The following is an actual comparison of the variability of carbon misfits for 8–12 and 70–75 carbon steels. The final carbon figure was taken for ten casts each selected at random from a large number of results. The tabulation is as follows :

A 8–12 Carbon Steel	*B* 70–75 Carbon Steel
10	76
8	75
10	72
11	70
10	74
10	70
9	76
10	77
10	74
10	74

It seems from inspection that the 70–75 carbons are more variable than the 8–12 carbons. The questions are : Is the difference " significant," and what are the population variabilities and the proportions to be expected outside specification on the basis of the practice at present in use ?

The procedure is one of the simplest of statistical techniques. In order to test the difference, the variance (standard deviation squared) is calculated for each sample, using the formula $\sigma^2 = [\Sigma X^2 - (\Sigma X)^2/n]/(n-1)$; where ΣX^2 is the total of the individual values squared, $(\Sigma X)^2$ is the total squared, and n is the number in the sample. The ratio of the larger to the smaller variance is then calculated, called F, and the value of F referred to the published F tables under the reference $N_B = n_b - 1$ and $N_A = n_a - 1$, where n_b and n_a are the numbers in the samples. In this case $\sigma_B{}^2 = 5{\cdot}96$ and $\sigma_A{}^2 = 0{\cdot}62$, so that $F = 5{\cdot}96/0{\cdot}62 = 9{\cdot}6$. $n_b = n_a = 10$, so that $n_b - 1 = n_a - 1 = 9$. Referring to $N_B = 9$, $N_A = 9$ in the F table, we find that the calculated value of F, 9·6, is highly significant, greater than the 1 in 100 value, so that the difference between the 70–75 and 8–12 variabilities as measured by their variances is real, and not merely an accident resulting from the use of a small amount of data. The 70–75 steel is more variable than the 8–12 steel.

In regard to the relation of the general performance to the specification, $\sigma_B = 2{\cdot}45$ and $\sigma_A = 0{\cdot}79$.

Assuming normal distributions with the total

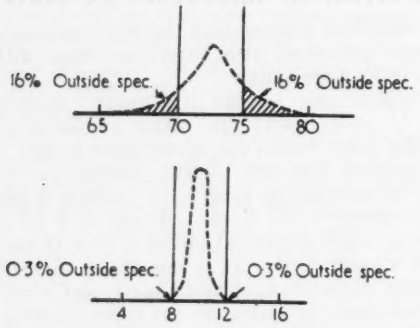


Fig. 10—Comparison of variability and proportion of misfit casts expected from 8–12 and 70–75 carbon steels

spread $(998/1000) = 6\sigma$, the total spread for B (70–75) carbon $= 6 \times 2{\cdot}45 = 14{\cdot}7$. Even if the average is at specification it is evident, as shown in Fig. 10, that the actual distribution is much wider than the specified spread, to the extent that the specification only accounts for 68% of the total. It follows that we can expect 32% misfit casts with current practice, even if the actual average is at mid-specification.

With A (8–12 carbon) the position is better; if the actual average is at mid-specification there should be only 0·6% misfits, since the total spread $= 6\sigma = 6 \times 0{\cdot}79 = 4{\cdot}74$.

THE CHI-SQUARE (χ^2) TEST—EXPECTED AGAINST OBSERVED RESULTS

One of the most useful of the statistical significance tests, since it has a wide variety of applications, is the chi-square test used for comparing expected and observed results when the data are the numbers of articles of different classes, *e.g.*, "good" or "bad."

An example taken from an actual large-scale use of the test illustrates the principles and the methods employed :

In an enquiry into factors affecting the production of defective rails, the following question arises : Is there a shift effect in the pouring of ingots, *i.e.*, in the three 8-hr. shifts making up the 24-hr. day, other things being equal, does each shift produce the same percentage of defectives ?

The method is to set out the defective rails for each shift, to calculate the number of defective rails which each shift would produce if all behaved in exactly the same way, *i.e.*, the average, and then to determine by the chi-square, on the basis that the results under examination are samples, whether the difference between the "actual" and "expected" of these samples represents a real difference between the populations from which they come. The formula is $\chi^2 = \Sigma(O - E)^2/E$ where Σ = sum of, O is an observed value, and E an expected value, χ^2 being the measure of the difference between "observed" and "expected."

The method of calculating the "expected" in the example is as follows. The total number of "good" rails is 5683, of "bad" rails 749, and of "good" plus "bad" rails, $5683 + 749 = 6432$, so that the average percentage of bad rails is $749/6432 = 11{\cdot}7\%$. If all the shifts behaved in the same way, each would produce 11·7% of its output as bad rails. The output for each shift is therefore multiplied by 0·117 to give the "expected" figure. Thus, shift A produced 1971 rails so that the "expected" bad rails $= 1971 \times 0{\cdot}117 = 230$, and the "expected" good rails $= 1971 - 230 = 1741$ (*see* example below).

The rule for looking up the χ^2 significance tables for a straightforward comparison of observed with expected is that N (in the tables) $= n - 1$, where n is the number of individual comparisons. Thus, in comparing observed with expected for three shifts, $n = 3$, so that N of the χ^2 tables $= 3 - 1 = 2$.

The total calculated value χ^2 is referred to the published χ^2 tables, these being used in the same way as the t and F tables already discussed ; *i.e.*, if the calculated value of χ^2 exceeds the value for a chosen probability level, the difference is "significant" or real ; if less, the difference is not proved.

In the case under consideration, $\chi^2 = 23{\cdot}80$ which

Example of χ^2 Test of Difference between Shifts

			Shift *A*	Shift *B*	Shift *C*	Total
Actual	Good	...	1685	2061	1937	5683
	Bad	...	286 = 14·5%	224 = 9·8%	239 = 11%	749 = 11·7%
	Total	...	1971	2285	2176	6432
Expected	Good	...	1741	2019	1923	5683
	Bad	...	230 = 11·7%	266 = 11·7%	253 = 11·7%	749 = 11·7%
	Total	...	1971	2285	2176	6432

$$\chi^2 = \frac{\Sigma(O - E)^2}{E}$$ where Σ = Sum of, O = Actual value, E = Expected value

	A	*B*	*C*	
$\chi^2 =$	1·80	+ 0·87	+ 0·10	
	+ 13·63	+ 6·63	+ 0·77	= 23·80 highly significant for $N = n - 1 = 2$

Example : Shift A : Good $= \frac{(1685 - 1741)^2}{1741} = \frac{56^2}{1741} = 1{\cdot}80$ Bad $= \frac{(286 - 230)^2}{230} = \frac{56^2}{230} = 13{\cdot}63$

exceeds even the value for the 0·001 level (10·83) for $N = 2$, so that χ^2 is highly significant and it is definitely established that there is a real difference between the shifts. A close analysis of the individual results is called for.

It is important to note that the χ^2 test is one of uniformity with a standard, that a low value of χ^2 indicates closeness to the standard, and a high value a greater departure from the standard. The sign of the difference from standard is not shown, however, and a high value of χ^2 may mean a big difference either upwards or downwards. For example, in the case under analysis, the total for χ^2 of 23·8 is made up as follows: Shift *A* 15·43, shift *B* 7·50, and shift *C* 0·87. This corresponds to the percentages shift *A* 14·5%, shift *B* 9·8%, and shift *C* 11%. Thus shift *B* is the best of the three, having the lowest percentage of defectives; shift *C* is in the middle, and shift *A* is the worst. Attention should be paid to shift *A*.

The value of the χ^2 test in an enquiry such as that into rail defectives is that it prevents what might be called unnecessary "witch hunting." If, for instance, an apparent difference between shifts proves not to be significant, so that in fact there is no real difference between them, or at least it is so small as not to be readily proved by the data available, there is no point in tackling, say, shift *A* which has appeared to be the worst. If, however, the difference is significant, and shift *A* is clearly the worst, there are grounds for serious technical enquiry. When one is examining a large number of variables, as in the defective-rail problem, it is useful to be able to neglect, at any rate to begin with, the factors which do not show a significant difference among their components, and to devote special attention to those factors which do show a significant difference.

As in other significance tests, the answer given by the χ^2 test is either that there is a significant difference or that the difference may exist, but if it does, the data are insufficient to give conclusive proof.

ANALYSIS OF VARIANCE

The *t* test is restricted to a comparison of two averages. When three or more averages are under examination, the technique of analysis of variance is employed.

In the *t* test the method is to relate the difference between the averages to its presumed standard error, and thus to determine whether the two averages could belong to the same population.

The same general principle is used in the analysis of variance. For example, in comparing the efficiency of operation of three open-hearth furnaces in attaining the mid-specification carbon value of (say) 73, *i.e.*, 0·73%, the results for three casts for each furnace might be as follows:

	Furnace *A*	Furnace *B*	Furnace *C*
Cast 1	71	72	77
Cast 2	72	73	76
Cast 3	70	74	74
Average	71	73	75·6

It would appear by inspection from the table that furnace *C* has a higher general average.

Analysis of variance would show whether the sample is so small that the difference between *A*, *B*, and *C* is apparent only and not real. If the difference is only apparent, special attention to *C* is not necessary.

Let us examine the tables of final carbons once more, with all the carbons less 70 to simplify the arithmetic:

Original Carbon less 70

	Furnace *A*	Furnace *B*	Furnace *C*	Range between Casts
Cast 1	1	2	7	6
Cast 2	2	3	6	4
Cast 3	0	4	4	4
Average	1	3	5·6	
		Range within Casts		
	2	2	3	

It will be noticed that the "between furnace" variability as measured by the range (highest less lowest) is considerable, 6, 4, and 4, whereas the "within furnace" variability is smaller, 2, 2, and 3. This difference in variability of "between" and "within" furnaces is caused by the fact that the general level for *C* is much higher than for *A* or *B*. The method of analysis of variance is to estimate the two variabilities, "between" and "within," as measured by their variances, and compare the two by the *F* test already described, to determine whether or not they come from distinct populations.

In the foregoing example the calculated values of the "between" and "within" variations are, σ^2 "between" = 16·45; σ^2 "within" = 1·45, so that comparing the two variances, $F = 16{\cdot}45/1{\cdot}45 = 11{\cdot}42$. Referring in the *F* table to N_1 ("between") = (number of furnaces − 1) and N_2 ("within") = 3 × (number of casts − 1) = (3 × 2) = 6, we find that the value 11·42 is well above the 1 in 100 significance figure, thus establishing that the "between" and "within" variances are from distinct populations, in other words, that the between variance is real so that the higher carbon figures for furnace *C* are typical and not accidental.

Essentially the same procedure, *i.e.*, comparison of variance by the *F* test, is applied whether the analysis of variance is a simple one-factor "between" and "within" as above, or a more complex, two-factor, three-factor, etc.

In the more complex analyses, in addition to testing for main effects, analysis of variance also tests whether the difference between groups is the same at each level of the blocks. This is brought out in the analysis as an interaction. The presence of a significant interaction indicates that the pattern of the main effect is not consistent everywhere, and breakdown of the data into groups is needed in order to find the nature of the inconsistencies.

One-, two-, three-, and possibly four-factor analysis of variance is valuable in sorting out effects as, say, between factories, between shops, between shifts, etc., but it is suggested that the simpler forms should be used wherever possible.

CORRELATION–REGRESSION—THE STUDY OF GENERAL RELATIONSHIPS

If it is found in the comparison of values from two properties *X* and *Y*, that low values of *X* seem to be

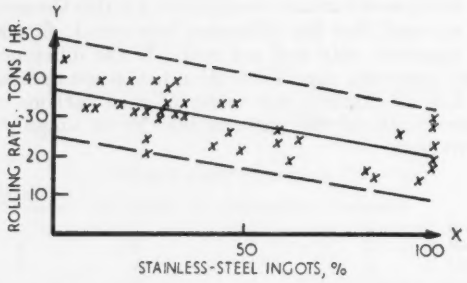


Fig. 11—Effect of varying percentage of stainless-steel ingots on rolling rate

associated with low values of Y and high values of X with high values of Y, or conversely that low values of X are associated with high values of Y and high values of X with low values of Y, the "correlation–regression" technique applies.

It has been very well known that stainless-steel ingots are more difficult to roll than ingots of mild or ordinary alloy steel. But it had not been previously possible to assess this factor in reducing the total rolling rate per hour in numerical terms, with the result that stainless-steel ingots provided an excuse for low rolling rate which might be suspected but could not be attacked. There is the world of difference between suspicion that an effect occurs, or even knowledge that it does occur without knowledge of its extent, and definite numerical certainty.

Figure 11 shows 37 actual results of rolling rates per hour plotted against the corresponding actual percentage of stainless-steel ingots rolled. The rolling rate per hour is taken as the actual tons rolled in an hour with a *pro rata* allowance for minutes lost in delays ; *i.e.*, if 25 tons are rolled in an hour having 10-min. delays caused by, say, roll changes, the rolling rate is taken as $25 \times 60/50 = 30$ tons.

For convenience, the percentage of stainless-steel ingots is called X, and the rolling rate (tons per hour) is called Y. It is useful to allot X to the cause and Y to the effect where possible, but it should be pointed out that it is not always possible to tell which is the cause and which is the effect ; sometimes X and Y may move together or contrariwise as the result of some other factor Z, which affects both.

Correlation–regression technique answers the following questions :

(1) How strong is the relationship between X and Y as measured by the correlation coefficient r which can vary between + 1, full positive relationship (as X increases Y increases), through 0, complete independence, to − 1, full minus relationship (as X increases Y decreases) ?*

(2) Is r significant within defined limits of risk, and if not significant, how much more data are required to give significance if r is real ?

(3) How much of the total variability of Y is explained by the relationship of Y with X ? The explained variability of $Y = r^2$, the unexplained variability of $Y = 1 - r^2$.

(4) What are a, the position of the line of estimate (regression line) and b, its slope, in the equation for the regression line $Y = a + bX$?

(5) Is b, the slope, significant, and if not, how much more data are required to establish its value ? This is statistically equivalent to (2) and either may be used in a simple, *i.e.*, two-way analysis.

(6) What is the standard error of the residual, namely s, and what is the tolerance, $\pm 2s$, above and below the regression line, so that an estimate of Y within the defined limits of risk may be made for any single value of X, *i.e.*, $Y = a + bX \pm 2s$?

(7) What are the practical limitations on the answers to (1) to (6) ?

The answers to the questions are as follows :

(1) It will be noted the first step is the calculation of r. This is derived from the formula :

$$r = \frac{\Sigma XY - \Sigma X \Sigma Y/n}{\sqrt{[\Sigma X^2 - (\Sigma X)^2/n][\Sigma Y^2 - (\Sigma Y)^2/n]}}$$

In the case under analysis $r = -0{\cdot}45$.

(2) The second step is to test r for significance from the published tables, the N being $n - 2$, where n is the number of pairs compared. If r is not significant, since a definite relationship between X and Y is not established, no useful purpose is served in proceeding to make the calculations to answer questions (3), (4), (5), and (6). The decision must then be made either to accept the relationship as indeterminate, or to secure the additional data required to prove significance on the assumption that the relationship exists.

A value quoted for r has no practical meaning unless it is stated that it is (*a*) not significant, (*b*) significant, or (*c*) highly significant, or alternatively the number of pairs of values upon which it is based is given, as the significance depends upon the number of pairs. For 52 pairs r is significant on the 1 in 100 level at $0{\cdot}354$, whereas for 10 pairs r must equal or exceed $0{\cdot}765$, and for 5 pairs r must equal or exceed $0{\cdot}959$ to be significant at the same level. Thus $r =$ (say) $0{\cdot}6$ may be not significant, significant, or highly significant, according to the number of pairs examined. The value $r = -0{\cdot}45$ of the example is highly significant for 37 pairs.

(3) The third step in logical sequence is to estimate how much of the total variability of Y is caused by the relationship with X, and how much remains unexplained.

In the previous example on the rolling rate of steels, r is significant and equals $-0{\cdot}45$, so that r^2 therefore equals $0{\cdot}20$; and $1 - r^2 = 0{\cdot}80$. Of the variation in Y, 20%—a fairly substantial proportion—is explained by X and this factor is therefore worthy of serious thought, but 80% still remains unexplained, and investigation of other factors is strongly suggested.

* Straight-line (linear) relationship is assumed. For treatment of curvilinear relationship, reference should be made to the textbooks mentioned in the Bibliography. Ezekiel's interesting graphical methods for curvilinear relationships have been used by a steelworks in the U.S.A., as described in a paper by A. P. Woods and C. R. Taylor, *American Institute of Mining and Metallurgical Engineers*, 1946, *Open-Hearth Proceedings*, vol. 29, p. 15.

(4) The next stage is the calculation of the slope of the line of estimate, or regression line, *i.e.*, the term b in the equation $Y = a + bX$. The value of b is calculated from the formula $b = r \cdot s_y/s_x$; r, s_x, and s_y are available from previous work. In the problem under analysis $b = -0{\cdot}17$, so that the rolling rate per hour drops by $0{\cdot}17$ tons per increase of 1% in the percentage of stainless-steel ingots rolled.

(5) Before proceeding to place the line by calculating a, it is necessary to check the significance of b by carrying out a miniature analysis of variance (this step need not be carried out if r has been checked in a two-way regression analysis). In the example, b is highly significant.

The term a is derived from the fact that the regression line passes through the average of X, namely $\bar{X}$, and the average of Y, $\bar{Y}$; $\bar{X} = 43{\cdot}8$ and $\bar{Y} = 29{\cdot}1$. Since the slope is $-0{\cdot}17$, $\bar{Y} = a + b\bar{X}$. Therefore $a = 29{\cdot}1 + (0{\cdot}17 \times 43{\cdot}8) = 29{\cdot}1 + 7{\cdot}45 = 36{\cdot}55$. The complete equation is therefore $Y = 36{\cdot}55 - 0{\cdot}17X$.

(6) The final step is to calculate the plus and minus tolerance limits for the regression line, taking the usual $2s$, 1 in 40 limits as for the control charts discussed earlier, where s is the standard error derived from the formula $s = (1 - r^2)s_y{}^2/n - 2$. In this case $s = 5{\cdot}55$ so that $2s = 11{\cdot}10$.

Combining the values found for a, b, and s, the complete estimating (regression) equation from which a value of Y may be predicted from a value of X, is $Y = 36{\cdot}55 - 0{\cdot}17X \pm 11{\cdot}10$.

(7) The practical limitation is that the deductions apply only within the limits of the data ; extrapolation is dangerous. This danger does not arise in the example as the data extend over the whole range.

Implications of the Analysis

Having now completed this straightforward two-factor analysis, the implications of the findings will now be examined more closely.

(1) Rolling stainless ingots has an adverse effect on rolling rate which is quite serious. Assuming average conditions, rolling 100% stainless-steel ingots would reduce the rolling rate from $36{\cdot}5 \pm 11$ to $19{\cdot}5 \pm 11$ tons/hr., *i.e.*, 40%. The shift foreman who has a large proportion of stainless-steel ingots has some grounds for not having a large output. He cannot now, however, stretch this excuse beyond the limits that have been found.

(2) The more important deduction arises from the value found for $1 - r^2$. The unexplained variations are 80%, so that the percentage of stainless-steel ingots, while important, is not the chief item which is causing variation in rolling rate. This emphasizes the point that if the unexplained $1 - r^2$ is at all a large proportion of the total variation of Y, a simple two-factor correlation–regression analysis is insufficient, and a more complete form of analysis is necessary

More extended correlation–regression takes two complementary forms, multiple—the effect of several factors on one factor—and partial—the effects from a multiple group, taken in pairs, with the remaining factors held constant by mathematical means. Both are powerful methods of great value in the examination of complex problems such as are typical of steelworks and blast-furnace practice. The formulae are not given here, but they are developments from the more simple treatment.

Practical Value of Correlation–Regression Analysis and Analysis of Variance

Possibly the greatest value of correlation-regression and of multi-factor analysis of variance lies in the fact that they can be used to deal with complicated works problems without the necessity to make any difference in practice. Until the arrival of modern statistical techniques, the method adopted for a complicated situation was to attempt to remove as many factors as possible so as to isolate the two of which the relationship was desired. It is extremely difficult and usually impossible to simplify a works problem completely in this way, and when it has not been possible the practice has usually been to make certain assumptions and proceed accordingly. Even if the factors can be reduced, as in a laboratory experiment, the result may not be a true reproduction of the works conditions which it is desired to analyse, and the results must again be interpreted with considerable caution.

Typical complex cases in which correlation–regression and analysis of variance have been applied are : (1) An investigation into blast-furnace conditions in which thirty-five factors operating simultaneously are considered, *i.e.*, coke shatter, burden conditions, blast pressure, volume, etc., and (2) an investigation of rail defectives in which 80 variables are analysed.

In the case of the effect of the percentage of stainless-steel ingots on the rolling rate per hour, mentioned earlier, a multiple regression analysis was made of the effects on rolling rate of the following : (1) Percentage of stainless-steel ingots, (2) percentage of small ingots of all classes of steel, (3) final size of billet rolled, (4) ingot temperature at rolling, and (5) stoppages. The crude *pro rata* system in use was inaccurate ; *e.g.*, if 25 tons are rolled in 50 min., it does not follow that $25 \times 60/50 = 30$ tons would be rolled in an hour.

The practical result was to supply a set of factors from which the recording clerk could assess the numerical effect and reduce the actual tons per hour to a rolling rate which could be compared with a standard, thus putting a powerful control in the hands of the management.

PART II—APPLICATIONS OF STATISTICAL TECHNIQUES AND THE RESULTING BENEFITS

The field of possible application in heavy industry for statistical methods, as set out in Part I, is very wide, and it is largely unknown.

The examples given below, which cover part of the explored field, are taken from the author's experience, supplemented from that of the Bristol Aeroplane Co.,

Ltd. Methods employed in these examples range from simple applications of straightforward statistical techniques described in Part I, to complex problems, the solution of which has called for the use of advanced and in some cases new statistical theory.

Benefits which accrue also vary. In some cases, there has been a definite and measurable cash saving. In others, new information otherwise unobtaintable has been provided for technicians, so that improvement in practice has become possible.

The examples are arranged in a uniform plan : Problem, preliminary work, statistical analysis, results, and benefits.

QUALITY CONTROL IN A MACHINE SHOP

Problem

The problem under consideration is the installation of statistical quality control in a machine shop on fine limits (Bristol Aeroplane Co., Ltd., Aircraft Division).

Preliminary Work

Much preliminary work has been done on the measurement of dimensions to a degree of accuracy not usually considered possible in routine machine-shop work.

Statistical Analysis

Quality-control charts have been installed on a considerable scale for capstan lathes and automatics. In the initial stage measurement was made to the nearest 0·0005 in. The charts had a limited use as the units of measurements were too coarse. By the use of comparators and special micrometers it is possible (and is now routine practice) to measure to 0·0001 in. and to use the measurements in quality-control charts. The example shown in Fig. 12 illustrates an application to automatics.

The methods used to measure to 0·0001 in. are : (*a*) Ordinary micrometers graduated to 0·0001 in., (*b*) bench micrometers with large-scale graduated drums, with fiducial pointer, and (*c*) specially mounted dial indicator. This dial indicator is essentially a cast base with two vertical brackets, one to hold a large-scale dial indicator graduated to 0·0001 in., and the other to hold a micrometer head. The head is set to size with slip gauges, the micrometer locked, and variations in measurements read off directly on the indicator. The value of this tool is its rigidity, ease of adjustment, range, and the fact that discarded micrometer heads can be used, since the graduations are ignored. For accurate measurement the ordinary dial-indicator stand fails because of the lack of rigidity of the pillar and the ease with which it can be put out of adjustment.

Range charts are not used. The range is indicated on the data sheet, and provided that it does not exceed one-third of the drawing limit and that the average falls within control, no action is taken. This is so readily assessed mentally that it is not considered worth while to plot a separate chart.

Results

The charts have been used in a number of ways apart from the straightforward application to the control of individual machines. An up-to-date record is kept of machine capabilities and work is allocated accordingly. Quality-control charts accompany 100% inspection for short runs, down to 100, each time an order is received, thus building up information about the characteristics of the machine.

It has been a noteworthy feature that very rarely does a chart show a trend of tool wear. It will happen when machining comparatively soft materials, but normally dimensions remain at mean level within the variability of the machine, and the first indication of trouble is a deterioration of surface finish. If action is not taken there is a dimensional collapse.

Benefits

The saving of inspection costs has been of the order of 5–10% on capstan lathes and 80% on automatics. Rectification and scrap have both been reduced by 90%.

An illustration of analysis may be helpful. Certain articles for a special purpose were ordered from a sub-contractor and the required limits were ± 0·001 in. Out of the first consignment a sample was picked at random, and an excellent distribution obtained, but one giving a manufacturing tolerance ± 0·0015 in. Further consignments gave ± 0·0019 in. No control existed at the sub-contractor's works, but from the records of the main contractors it was possible to show that the articles could be machined on their own automatics, and this procedure was adopted, with complete satisfaction.

SAMPLING OF SILICA BRICK

Problem

The next problem to be considered is the design of an economical sampling scheme to be used by a buyer of silica brick, who would reject an unduly bad consignment and not reject a reasonably good consignment, the requirement being that the specific gravity should be less than an agreed value.

Preliminary Work

As insufficient data were available arrangements were made with a manufacturer of silica bricks to study the production from his kilns.

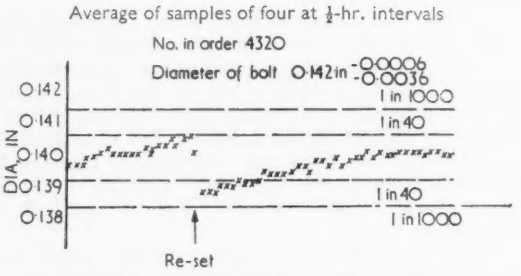


Fig. 12—Application of quality - control chart to machine-shop use with fine limits

Statistical Analysis

By using a statistically planned experiment a detailed study was made of 9 kilns and 15 positions in each kiln using only 135 bricks.

The resulting analysis of variance showed that of the total variation in specific gravity :

One-fifth was due to differences between kilns. No. 7 kiln gave bricks with a specific gravity 0·025 greater than the average.

One-fifth was due to differences between bricks from the centre, wicket, back, and the sides. Bricks from the wicket had an average specific gravity of 2·345 compared with 2·33 for the remainder.

One-tenth was due to differences between the top, middle, and bottom parts of the kiln. The middle of the kiln was hardest-fired. Sometimes the bottom was softer-fired as in kiln No. 6, and sometimes the top was softer-fired as in kiln No. 2. These occasional high specific-gravity bricks occurring at different parts in different kilns were attributed to particularly tight setting in those localities.

The remaining half of the variation could not be explained by differences between positions or by differences between kilns, and it has been suggested that it was probably brought about by such factors as variation in rock quality, chemical composition of the rock, or the grain-size used in the making of the brick.

The difference between kilns was removed and a comparison of the " within kilns " variability was made as in Fig. 13.

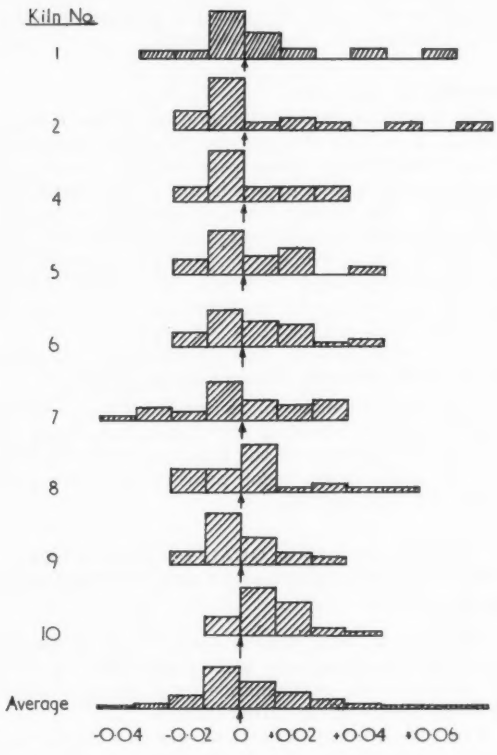


Fig. 13—" Within-kiln " variability

Results

Based on the foregoing information a sampling scheme was drawn up with a 5% " producer's risk " and 5% " consumer's risk " (the producer's risk is that good material may be rejected through sampling, and the consumer's risk is that bad material may be accepted through sampling). The scheme is : Take four bricks from a load (rail truck or lorry), measure the specific gravity of each brick ; if the average specific gravity is less than 2·365 accept the load ; if greater than 2·365 reject the load.

Benefits

The scheme has been adopted by several steelmakers in Sheffield for the silica bricks of the manufacturer who co-operated in supplying works data. The same scheme is also being applied to the bricks of other manufacturers, and detailed schemes suitable to the characteristics of any single manufacturer could be devised. Steel manufacturers who use the sampling scheme find that they are assured well-fired brick, and the brick manufacturers consider that the scheme is fair to them.

A valuable result of the introduction of the brick sampling scheme has been that three manufacturers of refractory brick in the Sheffield area have been stimulated into adopting statistical methods in their own control of quality.

FACTORS AFFECTING QUALITY OF BESSEMER RAILS

Problem

The problem is to assess in order of importance the factors affecting the quality of acid Bessemer rails, and to provide guidance for technical management in improving practice.

Preliminary Work

After examination, by the statistical staff, of the technical literature on acid Bessemer pouring and rolling practice, and of previous technical investigations, works procedure, and system of shop records at the works concerned, it was agreed with the management that :

(1) The system of records in use was thorough, but for statistical purposes a single cast-history card should be designed and put into use.

(2) In addition to existing information, temperatures should be taken and recorded (*a*) in the Bessemer converter, (*b*) at ingot pouring, and (*c*) at the cogging mill.

(3) The system of identification, both for ingots between stripping and rolling, and of rails at the hot-stamping stage should be tightened.

The above recommendations were put into effect.

Statistical Analysis

The statistical work was divided into two sections, a preliminary study of 250 casts, followed by a study of 300 further casts, with special emphasis on points suggested by the preliminary work.

Since a large amount of data was to be handled, the first stage was to design two Hollerith cards. The first was to take all information from the cast-history card relating to the cast as a whole in relation to the percentage of defectives per cast, *i.e.*, mixer-iron analysis, Bessemer and ladle additions, ingot pouring time, track time (ingot pouring to soaker), etc. The second card dealt with particulars relating to individual ingots and the rails rolled from those ingots in relation to the faults found in rails, *i.e.*, order of pouring ingots, pouring conditions (stream, use of oxygen, etc.), mould conditions, position in soaker, cogging temperature, part of ingot from which rail comes, type of fault found in rail, etc.

The Hollerith machines were used not only for sorting but for calculating sums of squares required for regression analyses.

The statistical analysis was on the whole of two main types. For the " two-category " information, *i.e.*, rails are " good " or " bad," use was made of the chi-square technique on the lines of the example given in Part I to find the apparent effects. In order to disentangle these effects use was made of minimum $\chi'^2 = (O - E)^2/O$ instead of $\chi^2 = (O - E)^2/E$, on the lines of analysis of variance. This new technique was worked out by M. W. T. Hale.

The following is an example of the need for this disentanglement, and incidentally of the value of statistical methods in preventing executives from making wrong deductions. A group of defective rails might be found under the heading " Without Wood-Wool " when that is being studied, and also under the heading " Cracked Moulds " when that is studied, and so this same group of ingot moulds would lead to two different conclusions, *viz.* : (1) That not using wood-wool gives defective rails, and (2) that using cracked moulds gives defective rails. These factors must be disentangled to find out which or both is really responsible.

Correlation–regression methods were used for all information relating to a continuous scale, *i.e.*, mixer-iron analysis, silicon 1·8% to 2·9%, etc. The work was divided into sections such as mixer iron, factors associated with the Bessemer blow, additions, etc.

Any significant results from these partial analyses were included in a subsequent major analysis.

Results

As was expected, most of the results confirmed technical experience. The valuable feature of those results that were not new was the distribution of the emphasis. Where so many factors may affect quality, it is useful to management to know which items warrant special attention. It was known, for example, that in pouring ingots the use of warm graphite-washed relatively new moulds having new stools, using wood-wool to prevent splash, and with the teemer giving a central stream without spread, would give better steel than the use of moulds that were cold, non-graphite-washed, etc. The relative importance of these factors had not been known, however, and is now established. A useful item was the indication of a limit to the useful life of an ingot mould as used for rail steel, moulds used over this limit tending to produce an undue percentage of defectives.

In addition to the " confirmatory " information, there were a number of additions to knowledge of the process, all of which could be put to practical use. It was found, for instance, that there was no appreciable difference between shifts (groups of men) in regard to the Bessemer " blow," although this had been suspected, but that there was a shift difference in respect to pouring ingots, and further that this difference could be attributed largely to certain features in the practice of one teemer foreman, particularly in respect to the speed of pouring. Another useful new piece of information was that there was an appreciable difference in quality of ingots from different soakers, and from different sides of each soaker.

A point of general importance arises in connection with one deduction.

In dealing with the stream from the ladle to the ingot mould, the largest percentage of defectives was associated with the use of oxygen. This does not mean, as might be supposed at first glance, that the use of oxygen is bad, but that the condition which necessitates the use of oxygen, a " difficult " ladle stopper, is bad. No steel man would make the wrong deduction in this case, but others are not always so straightforward, and the moral is pointed out that careful thought is always necessary.

Benefits

The results are being actively used by the management in a number of ways ; two may be mentioned. Special attention is being paid to those features in ingot-pouring practice which are given particular emphasis. The teemer foreman who has been associated with a larger percentage of defectives has been shown the error of his ways, and the percentage of defectives associated with him has fallen. Ingot moulds are not to be used for rail steel over the economic limit suggested in the report.

Chart control is being organized for each important factor in the process. These factors include :

(1) Control chart of defectives by (*a*) blower shift, (*b*) ingot-pouring shift, and (*c*) soaking pit.
(2) Temperature of the Bessemer blow and ladle.
(3) Times of (*a*) ingot pouring, (*b*) track time, and (*c*) soaking time.

EFFECT OF COKE QUALITY AND OTHER VARIABLES ON BLAST-FURNACE PERFORMANCE

Problem

The next problem considered is to check whether suspected effects of coke quality and other variables on blast-furnace performance exist or not, and to provide improved operating indices.

The blast-furnace concerned operates on rich ores and is not subject to the checks and slips experienced with lean ores.

Preliminary Work

After discussions were held with the technicians, it was decided that routine works weekly data would be suitable for analysis, and that controlled experiments would not be necessary.

Statistical Analysis

The analysis was made on two years' weekly data. The first stage was to construct a table of " raw " correlation coefficients and to discuss this table with the works technicians. Further work developed from these preliminary results, techniques employed including multiple regression, lag correlation, and the theory of index numbers.

Results

Among the preliminary results were that for this blast-furnace the — ½-in. shatter is more important than the 1½- and 2-in. shatter, and that the time lag of coke effects on blast-furnace performance is much greater than had been suspected. Three indices were provided :

(1) Blast-furnace performance. This is an index used by the management to express in one figure the effectiveness of the furnace. It is obtained by applying correction factors to the output per ton of coke to provide for variations in coke quality, iron quality, and ore quality. The amended value is then compared with the results obtained during a specified base period.

(2) Coke quality (in this case incorporating both chemical and physical properties).

(3) Effect of sulphur in coke and ore and of slag volume on furnace performance.

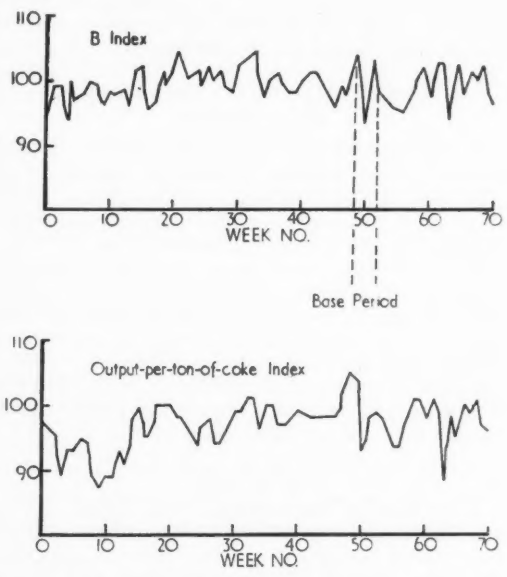


Fig. 14—Comparison of *B* index and output-per-ton-of-coke index for blast-furnace performance

These indices are mainly for the use of higher management, and to indicate long-term trends and/or oscillations.

Figure 14 shows a comparison of the suggested index of blast-furnace performance, *B* index, with an output-per-ton-of-coke index for 70 weeks. Several comparisons can be made. The excessively low values of the output-per-ton-of-coke index for the first few weeks were not representative of the actual furnace performance which was actually only slightly below full efficiency. Again, the downward trend shown during the last few weeks on the graphs for the output-per-ton-of-coke index does not correspond to the true position which is reflected by the graph for the new index. Much of the apparent variation shown by the output-per-ton-of-coke index was caused by shortage of coke reflected in a low rate of drive, and inferior quality of the coke available for use.

Benefits

The principal advantage of this type of statistical analysis is that effects which overlap may be estimated and allowed for, whereas the theoretical formulae only supply corrections which tend to be added, so that the same effect may be used several times. This feature has been of particular importance in calculating the three operating indices in which all the known relevant effects have been allowed for at their estimated correct values.

CONTROL AND INSPECTION OF HOT-ROLLED STEEL BARS

Problem

The final problem considered here is the determination of the characteristics in regard to width and thickness of hot-rolled bar in order to substitute if possible a method of sampling inspection for 100% inspection.

Bars are rolled hot from billets to sizes varying from about ½ to 3 in. round, flat, and hexagonal. The hot bar after rolling is transferred to one of two cooling beds, and when cool is sheared into lengths as ordered by the customer.

Before this investigation was carried out all bars except very cheap " qualities " were 100% inspected, the 100% inspection taking place some considerable time after rolling.

Preliminary Work

The preliminary work in this instance consisted of discussions with mill management, inspectors, charge hands, and rollers, in order to gain some insight not only into the technical aspects of the problem, but into the points of view of all those concerned.

Statistical Analysis

The first stage consisted of an experiment planned on statistical lines to answer the following questions :

(1) Do the dimensions of the back end of a bar give a good estimate of the general dimensions of that bar ?

(2) If they do, do they give a good estimate of the dimensions of adjacent bars ?

(3) Assuming that satisfactory answers have been given to the first two questions, does the observation on a quenched hot test-piece give the same value as that on a slowly cooled test-piece at the same place ?

(4) Is the product on the two cooling beds the same ?

An experiment was planned to give the answer to these questions.

The bars were rolled from billets which were cut into two halves so that one cooling bed received all the front halves of billets and the other received all the back halves.

When the back end (rear end) of the hot bar was sampled, the bar was marked and followed through to the shears. At the shears a test-piece about 12 in. long was taken from the front end of the bar and the five adjacent bars and carefully marked. Then, after a number of lengths had been cut off, further test-pieces were taken from the same bars, approximately a third of the way along. Similar test-pieces were taken two-thirds of the way along and finally from the back end. A similar series of test-pieces was taken from the other cooling bed. On each test-piece measurements of width were made at three places and measurements of thickness at three points across the bar at each of three positions. Thus for each cooling bed there were 6 (bars) $\times$ 4 (positions in bar) test-pieces corresponding to each " hot " sample and three width observations and nine thickness observations per test-piece. The two cooling beds were sampled at as near the same time as was possible.

Results

The results of the experiments were that the sample from the back end of the bar was found to be representative of the whole of the bar except the front end which had a much greater variability than the rest of the bar.

It was therefore possible to devise a straightforward sampling inspection system for width and thickness of bar, and after a trial lasting for several weeks this system was put into use. It is still in use.

The essentials of the scheme are as follows : From the back end of every sixth bar a test-piece is taken as the bar emerges on to the cooling bed. The test-piece is quenched, measured, and examined for steel faults. The results of the test are made known to the roller and to an examiner at the cooling bed and shears by a signalling system using red and green lights which was installed for the purpose.

When the green light is showing, indicating a satisfactory hot sample, the examiner at the cooling bed and shears examines all the bars visually for steel faults, and gauges only the front ends of bars to decide which bar lengths must be sent for 100% inspection on the table. Those bars free from fault are loaded into wagons and sent out to the customer.

When the red light is showing, all the bars are submitted for 100% examination at the table.

Benefits

The prime object in installing the scheme was to improve quality. The actual result is that the quality began to improve as soon as the system was installed, and the improvement has been maintained. Rejections by customers have decreased by about 75%. The improvement in quality applies not only to gauging of dimensions, but to inspection of steel faults which continues on the 100% basis as before.

At first sight it might seem odd that sampled material should be better than 100% inspected material, but there are two cogent reasons for the improvement. The first is that, whereas formerly the men who carried out the 100% inspection had a large proportion to examine that was in fact good, there was little to find, and that little might escape notice. Now all material sent for 100% inspection is suspect, and the inspectors know that very careful examination is necessary. The second reason is that whereas under the 100% inspection system since there was a considerable time lag between rolling and inspection there was no quick indication to the roller if dimensions began to go out of gauge, he is now kept constantly in touch and receives a warning signal when the gauger at the shears finds that 100% inspection is necessary.

In addition to the benefit of improved quality, there have been considerable savings to the management as a result of the substitution of sampling for 100% inspection. This saving is estimated to be of the substantial order of £5000 per annum.

A second economy, which has not been estimated in cash, is that of space, and hence in overhead costs. Under the former system, steel bars were not inspected until some time after rolling, and had to be stored temporarily. Under the present system, the bulk of the output passes sampling inspection and can be, and usually is, despatched almost immediately to the customer. This calls for less storage space, and the prompt delivery is liked by the buyer.

PART III—ORGANIZATION

MAIN POLICY

Success or failure in the use of statistical methods depends not only on the person who carries out the work, but on higher management, which has its own very definite responsibility. Management must believe in and be solidly behind the statistical work.

While strong and consistent backing is essential, it must be realized that, like other management tools, statistics has its limitations. Much harm has been done in recent years by the making of extravagant claims, and hence by undue optimism. Where statistics have been successful the beginning has been modest, and the statistical department has been asked to walk before it has been asked to run.

STAFFING

Fully trained mathematical statisticians are not available at the present time except on rare occasions. Since this will continue to be the case for some years to come, what is the best procedure to follow in building up a statistical department ?

It is essential that the statistical work should be

incorporated with that of the organization as a whole. A free-lance statistician would enjoy apparent freedom, but he would be very much limited by lack of contact, particularly with the higher level of executives.

Whichever department is selected to carry out the statistical work, the main essential is that the head of that department should be interested in the possibilities, and be prepared to take whatever action is necessary in order that the work shall be successful. This would involve an undertaking on his part to do a certain amount of study of the basic theory behind present-day statistical techniques.

So long as there is a technical outlook, the choice of the department which is to provide the statistical service does not greatly matter. The author has seen successful statistical work under the production or development engineer, the chief inspector, or the research department.

The working statistician, or statisticians, chosen to carry out the investigations, and to instal and watch the control charts, etc., should have the following qualifications :

(1) Ability to understand and appreciate the point of view of the practical men who are to be helped, together with the power to explain statistical methods in non-statistical language.

(2) Ability to analyse the problem, to devise methods for its solution, to make recommendations when the statistical work is completed, and to make a clear and simple report.

(3) Knowledge of the technical processes to be studied.

(4) A sound knowledge of mathematics.

The ability to mix with and get on with the practical men and to explain to them what is going on is extremely important. The same thought was recently expressed by Dr. H. Channon, Director of Research at Messrs. Lever Bros., Ltd., in an address in which he said that the most important characteristic of any research man is " miscibility," in other words, the ability to mix. The successful industrial statistician must be a practical psychologist. He must realize that the departmental managers, foremen, and inspectors, and others with whom he has to deal, are able men in their own right, and he must continually study their point of view. He must avoid " blinding with science," and put his explanations in practical terms.

The ability to size up a problem depends largely upon knowledge of the technical processes. The work of a statistical department in a steelworks is much more than the mere examining of data by statistical techniques, whether these data come from experiments or from records, and it is a form of what is now called operational research.

Although much statistical work is quite simple from the mathematical point of view, a sound knowledge of the background is necessary for use when the more awkward types of problem present themselves.

The general deduction from the above list of requirements is that the person to be trained for statistical analysis and control in steelworks and heavy industry should have the technical outlook. He should be preferably an engineer, metallurgist, chemist, or physicist. The pure mathematician may become a successful industrial statistician, but on the whole it is easier to turn an engineer into a statistician than a statistician into an engineer.

AUXILIARY STAFF AND EQUIPMENT

It is accepted in existing heavy-industry statistical departments that the greatest part of the time on any given job is taken up by the working out of the calculations. So much is this the case that the purchase of an electric desk calculating machine which multiplies and divides as well as adds and subtracts is fully justified *

The great virtue of the desk calculating machine is that it provides for two sets of units as in a correlation–regression problem, the sum of units, squares, and cross-products, in one series of operations, *i.e.*, it gives ΣX, ΣY, ΣX^2, ΣXY, and ΣY^2 in one combined operation instead of five separate operations, as in the following example :

X	Y
20	4
15	5
12	7
10	9

$\Sigma X = 57$, $\Sigma Y = 25$, $\Sigma X^2 = 869$, $\Sigma Y^2 = 171$, $\Sigma XY = 392$.

Where the Hollerith punched-card equipment is available it can be used to great advantage, not only in preliminary sorting of mass data, but also in calculating sums of units and their squares as above, and in other calculations. The use of the Hollerith for statistical work is a recent development ; those interested should apply for information to the Mathematics Division, National Physical Laboratory, Teddington. The Powers-Samas equipment may be similarly employed.

As the work develops it will be found that computing increases more rapidly than the rest of the work. It will be inefficient for the trained statistician to be spending a large proportion of his time on computing ; and when this stage is reached, it is very well worth while to engage one or more computers.

ORGANIZATION OF THE WORK

Where the statistical work is being undertaken by the production, development, or research departments it is suggested that the addition of statistics should be regarded as a widening of the methods already used, statistics being one more tool added to the equipment. This procedure has the advantage that the new methods are fitted in with and take advantage of previous methods.

In general, there are three types of works problem for which statistical techniques are helpful : those in which an investigation may lead to an improved running control, which may or may not be statistical in form ; those in which effects are isolated and

* Electrically operated non-printing desk calculating machines available are : Friden, Marchant, Monroe (U.S.A.), and Madas (Switzerland). The cost is £150–£350, according to whether the machine has semi-automatic multiplication (on which the dials must be watched) or fully automatic multiplication.

assessed, leading to the benefit of improved or additional technical knowledge ; and those in which information is to be presented to management in a more forceful, simple, and accurate form in order to save them from unnecessary worry or undue elation, and to save their time.

Until higher management and departmental heads appreciate how statistics can help them, they cannot be expected to suggest problems to the statistical department. An early step after the establishment of such a department, therefore, should be one or more informal talks to departmental heads and staff concerned, on the simplest possible lines, on the benefits of statistics in works management and control. Particular emphasis should be placed on the essential point that present-day statistics are an approach to knowledge of large numbers through a sensible use of sampling.

Discussions with the technicians are the life blood of a statistical department. They should form the first step in any investigation and take place at frequent intervals while it is in progress. The result of a steady following of this policy is that the statistician and the technician are closely knit as a working team, pooling their knowledge to the common good.

The procedure adopted in tackling a job should consist of the following :

(*a*) Study of all available information, and discussions with technicians.

(*b*) Planning the statistical work.

(*c*) Sorting, etc., by Hollerith, computing by desk machines, statistical analysis, translation of statistical results into practical conclusions, and the report.

REPORTS

The guiding principle in the preparation of reports should be that they are to be useful to the executives to whom they are addressed. A report should be written as though addressed personally to the chief executive concerned.

Management and technicians wish to know mainly what proposals are being made to improve practice. Reports should therefore contain recommendations as well as results. The difference between a report which contains results and one which contains results and recommendations may be the difference between a report which is "interesting" and one which is "useful."

Reports should be written in ordinary English and contain as few statistical expressions as possible.

If the report is of any length it should be prefaced by a summary containing the object, results, and recommendations.

The statistician should remember that he must always translate his statistical results into practical results. There is little object in presenting the steelworks manager with a regression equation such as $Y = 36{\cdot}55 - 0{\cdot}17X \pm 11{\cdot}0$. The valuable information which this equation does express must be presented in the form which would be most useful, in this case, that "an increase of 1% of stainless-steel ingots decreases the rolling rate by 0·17 tons/hr., from a maximum of 36·55 tons/hr. for zero percentage of stainless-steel ingots, with a plus or minus tolerance for any single value of the percentage of stainless-steel ingots rolled, of 11 tons/hr."

Reports should always be submitted in draft to the technical departments concerned, such as melting shop, billet mill, etc., and fully discussed prior to issue. With this practice the department in question will always feel that they are having a square deal even though their criticisms are not always accepted.

Acknowledgments

Thanks are expressed to Mr. F. H. Saniter and the Directors of The United Steel Companies, Ltd., for permission to publish, to the Bristol Aeroplane Co., Ltd., Aircraft Division (through Mr. K. Hayward and Mr. E. W. Lott), for a contribution relating to experience with statistical methods, to Mr. L. H. C. Tippett, of the British Cotton Industry Research Association, for constructive criticisms and suggestions, and to the author's assistants, Mr. W. T. Hale and Mr. J. Murdoch, for further suggestions and checking.

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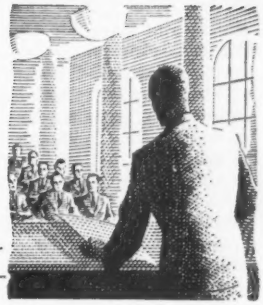
DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Spring Meeting, 1948

Joint Discussion on the Papers—

THE PRODUCTION OF NODULAR GRAPHITE STRUCTURES IN CAST IRONS*

by H. Morrogh and W. J. Williams

THE CARBIDES IN IRON–CARBON–SILICON ALLOYS AND CAST IRONS†

by D. Marles

Mr. **W. J. Williams** (British Cast Iron Research Association), in presenting the first paper, called attention to the following errors in the paper as printed in the March, 1948, issue of the *Journal*:

Page 309, right-hand column, in the analysis of test-bars, the sulphur figure should read 0·01% instead of 0·10%.

Page 311, bottom of the left-hand column, the sulphur figure given as 0·14% should read 0·014%. In the right-hand column of the same page, the sulphur figure given as 0·10% should read 0·01%.

Page 313, left-hand column, the sulphur figure given as 0·20% should read 0·02%.

Page 315, in the inscription to Fig. 33, for "hypo-eutectic iron" read "hyper-eutectic iron."

Mr. **D. Marles** (British Cast Iron Research Association) briefly introduced his paper.

Dr. **L. B. Pfeil,** O.B.E. (The Mond Nickel Co., Ltd.), who opened the discussion, said: I have studied the paper by Mr. Morrogh and Mr. Williams with great interest, and have been much impressed by the detailed studies which they have been able to complete in a short period of time. Last year these authors provided the Institute with a valuable account of factors influencing the form of graphite in nickel–carbon, cobalt–carbon, and nickel–iron–carbon alloys. The present paper represents an important advance in knowledge towards a goal for which many have striven, namely, the commercial production of cast irons which in the as-cast condition have a nodular graphite structure.

Amongst those who have worked with this objective are the research staff of the International Nickel Company, who have had the subject under investigation for a number of years. The nickel industry has become increasingly familiar with magnesium as a neutralizer of sulphur, ever since Fleitmann in 1879 demonstrated its effects. The International Nickel Company included in its research projects an investigation of the influence of magnesium in cast iron, and a process, having some features in common with the work which the authors have described, has been worked out for the effective treatment of cast iron by magnesium to produce the spheroidal graphite structure without heat-treatment.

The process is based on the introduction into molten iron of a magnesium-containing addition alloy. Thus, for example, by the use of nickel–magnesium it is a practical proposition to introduce magnesium into molten iron under ordinary commercial conditions. As in the case described in this paper, a first small addition of magnesium has a desulphurizing effect. A little more produces the type of structure referred to by the authors as "quasi-flake," while a larger addition changes the structure over completely to the spheroidal graphite form. The progessive change in structure is accompanied by increase in strength rising from the level of the base iron to several times as high, and simultaneously the impact properties are improved. Again, if the treatment is applied to a low-phosphorus iron some elongation is exhibited when the graphite is nodular, and with heat-treatment substantial elongation can be developed.

From what we have heard from the authors and from what has been done elsewhere, it appears that engineers can reasonably anticipate having at their disposal in the near future what almost amounts to a new alloy. This new iron should play an important part in engineering construction in the future. Much effort is still required, however, on the part of metallurgists in studying fundamental aspects of graphite formation in cast iron, as well as in completing the urgent task of converting the findings of the laboratory and of pilot-scale experiments into full and effective economic production. This paper indicates that we can continue to look to the British Cast Iron Research Association to play an important part in this promising field.

Mr. **W. S. Owen** (Liverpool University): I have read the paper by Mr. Marles with very great interest, and I am somewhat disturbed to find that the author has concluded that it is necessary to introduce a new phase into the metastable iron–carbon–silicon system in order to interpret the microstructures of his alloys.

Adopting the view that the iron–carbon–silicon alloys can be represented by the conventional double-ternary diagram representing the stable and metastable

* *Journal of The Iron and Steel Institute*, 1948, vol. 158, Mar., p. 306.

† *Journal of The Iron and Steel Institute*, 1948, vol. 158, Apr., p. 433.

states, and assuming that the peritecto-eutectic point lies somewhere in the region of 6–8% of silicon, it is not surprising to find complex constituents of iron and silicon (possibly containing carbon) in alloys containing more than that amount of silicon, especially when cooled under "non-equilibrium" conditions. But it is surprising to find an "iron–silicon–carbide" phase reported in an alloy containing only 2·5% of silicon, even if allowance is made for the relatively rapid rates of cooling employed. The appearance here of such a phase, in addition to the generally accepted carbide phase, seems to demand a drastic alteration of our present ideas concerning the general form of the diagram.

If it is postulated, as it is in the paper, that two carbide phases separate from the liquid, it would seem that there must be four phases present when the eutectic reaction occurs and that this reaction takes place at an invariant point. It is surprising that no indication of this is found in the thermal-analysis data of earlier workers. A. Kříž and F. Pobořil used alloys of impurity comparable with those used by Mr. Marles, and experimental conditions such that alloys containing up to 6% of silicon solidified in the metastable form, yet they do not record any observations which suggest that the eutectic reaction is non-variant. The diagram which they produced agrees with the general form suggested by Scheil largely from theoretical considerations, in which he assumes that the solid phases present at the four-phase plane are solid solutions of carbon in α and γ iron and a phase based upon Fe_3C and containing silicon. I should be interested to know the alterations which the author would propose in the general form of the ternary metastable diagram in order to accommodate the new "iron–silicon–carbide" phase.

Although the author rejects the view that the non-heat-tinting constituent is a solution of silicon in the usual iron–carbide phase, I am inclined to the opinion that it may be more reasonable to attempt to explain the photomicrographs on this basis. The idea that the carbide phase in the ternary iron–carbon–silicon system contains silicon and can exist over a range of silicon and probably carbon contents, has been widely accepted by other investigators in this field. In view of the considerable changes in the composition of the melt which may ensue over a small temperature interval of the eutectic reaction, appreciable variation of silicon content within the carbide phase is to be expected under the conditions of cooling described in these experiments. There are known examples of such a segregation within a phase presenting the appearance of two separate phases under certain conditions of metallographic preparation. I suggest that the question of the number of phases that are actually present could possibly be decided by an X-ray examination of the alloys.

Any discussion of the carbide phases in cast iron is bound to be inconclusive, as our present knowledge of the stable and metastable iron–carbon–silicon systems is based upon inadequate experimental data, particularly in the peritecto-eutectic and higher-silicon regions. Before really satisfactory interpretations of structures such as are described in this paper can be made, extensive thermal analysis of high-purity alloys, coupled with an X-ray investigation of the phases occurring in the solid state, is necessary. My colleagues and I are already working along these lines, and hope to contribute, at a future date, some of the data required.

Mr. **M. M. Hallett** (Sheepbridge Stokes Centrifugal Casting Co., Ltd.): The paper by Mr. Morrogh and Mr. Williams is an event in the cast-iron world; it represents the culmination of a long and arduous investigation, pursued with great skill over a considerable number of years. Those of us who have been in touch with the work and who have watched its gradual development from the initial conception up to its present state of development have admired very much the patience and skill shown by the authors in pursuing their alternative lines of investigation. The authors deserve the greatest credit for their contributions to both theoretical and practical knowledge.

Our excitement over the high tensile-strength levels which can be so readily obtained by this process should not, however, blind us to the very great advance which has been made in the theory of graphite formation, and I think that the importance of this theory may be even greater than its immediate practical application.

I wish to confine my discussion to a few of the more theoretical points, merely remarking, on the practical side, that our experience confirms the claims of the authors. Nodular cast iron can be produced in the foundry with a tensile strength of at least 35 tons/sq.in. in 2·1-in. test-bars and with an almost entirely pearlitic matrix, as is suggested by Table XV of the paper.

Much work needs to be done in determining the exact mechanism of the formation of nodular graphite and the temperature at which it forms. We are looking forward to hearing from Professor Mehl in his Hatfield Memorial Lecture an account of the rates of nucleation and growth in the decomposition of austenite, and I feel that the application of the same outlook to the study of the formation of nodular graphite is likely to be very fruitful. The experimental difficulties are obviously formidable, but until we can express the process in a quantitative fashion I do not think that we can feel entirely satisfied.

The paper demonstrates the high level of mechanical properties associated with nodular graphite. In his presentation, Mr. Williams mentioned the good properties which can be obtained with the type of graphite which the authors term "quasi-flake." The following results emphasize that point. They were obtained on a crucible-melted hematite pig iron of high carbon and silicon contents, cast partly into centrifugal castings and partly into test-bars in sand moulds. The tensile-strength determinations on the centrifugal castings were made on the ring form of test-piece, while the percentage values quoted for ferrite are simply the observer's qualitative estimate:

Mischmetall Addition, g./100 lb.	Test-Bars ($\frac{1}{2}$ in. dia.)		Centrifugal Castings		
	Type of Graphite	Ferrite, %	Type of Graphite	Ferrite, %	Tensile Strength, tons/sq.in.
25	*F*	7	*Q*	15	29
35	*F*	20	*Q*	60	53
45	*N*	50	*N* + carbide	10	38

F = flake graphite. *Q* = quasi-flake graphite. *N* = nodular graphite.

Two points are worthy of comment. The centrifugal castings respond to smaller additions of mischmetall than the sand castings. This may be due to the effect of the more rapid cooling in stabilizing eutectic carbide in the same way as cerium and so adding to the effect of the cerium present. Secondly, the peak of tensile strength in the centrifugal casting occurs while the graphite is still in the quasi-flake form. The comparison is complicated by the presence of massive carbide with the nodular graphite, but it is clear that the quasi-flake graphite is associated with good mechanical properties. I suggest that the good result may be due to modification of the points of stress concentration. Normal flake graphite leads to marked concentration of stress at the sharp ends of the flakes. Microscopical

examination of the quasi-flake graphite in the samples above shows that the ends of the flakes tend to be rounded and probably modify the stress concentrations in the same way as nodular graphite. Similarly, in the case of the 2·1-in. test-bars with a tensile strength over 35 tons/sq.in., to which I referred earlier, at least half of the graphite was in the quasi-flake form. It is not suggested that the quasi-flake graphite gives such good results as the nodular, but merely that quasi-flake is superior to normal flake graphite.

The high proportion of ferrite in cerium-treated iron is puzzling. It can hardly be due to any direct effect of cerium as an alloying element. The paper refers to the "spheres of influence" of the spherulites. One can understand that these zones are wide at the high temperature of formation of nodular graphite, but it is difficult to imagine an equal area of influence at the lower temperatures of formation of ferrite. In the presence of supercooled graphite flakes, it may be presumed that the flakes have an inoculating influence on carbon precipitated from the austenite at the critical point on account of the short distance the carbon atoms would have to travel to reach the nearest flake, but this explanation can hardly apply to the case of nodular graphite where the distances are much greater. Possibly the graphite nodules dissolve in the austenite much less readily than do graphite flakes, so that the initial impoverishment of the austenite in carbon, arising from the complete precipitation of the carbon in the carbide eutectic as nodules of graphite, is never corrected by resolution of carbon in the surrounding matrix during subsequent cooling. It would be interesting to have the authors' views.

Mr. **K. H. Wright** (British Rollmakers' Corporation, Ltd.): We who are connected with the manufacture and metallurgy of cast iron must express the greatest admiration for the work on graphite formation by Morrogh and Williams.

From the earliest days in the history of cast-iron metallurgy, experiences and anomalies have been reported which do not seem to fit in with any preconceived theory. The term "inherent properties" has been used to cloak a profound ignorance of the fundamental laws governing solidification and graphitizing mechanisms, and I feel that whilst these present researches have given the industry a new material with which to work, the results are capable of a much broader interpretation and ultimately will lead to a more complete understanding of these anomalies frequently encountered in normal flake graphite irons.

Several of these anomalies are certainly unrelated to the chemical analysis of the metal, for example, why should one iron chill more readily than another of apparently identical composition? What is the main factor controlling the spread and size of the "mottles" in chilled castings, and why do certain mixtures result in undercooled structures even in very large masses above 30-in. section thickness?

We can take precautions dictated by long experience in order to avoid many of the undesirable phenomena, but we still do not fully understand the underlying reason for their occurrence.

Some years ago I examined a piece of cannon made about the time of Lord Nelson. This analysed total carbon 3·88%, silicon 0·25%, sulphur 0·036%, phosphorus 0·964%, and manganese 0·51%. The section was approximately 1¼ in. thick and the fracture was dead grey with a combined carbon of 0·68%. Today I suggest this analysis would result in a mottled if not a white fracture in such a section.

There is a further interesting report which I think is worth repetition. Schwartz* reported that during the course of experiments with an extremely low-sulphur-content blackheart malleable iron, melted in a basic furnace, he had cast from the same hand ladle two identical castings, one of which solidified white and the other grey. Schwartz himself could give no explanation, but again the sulphur content was extremely low—I think of the order of 0·01%. No stability of primary graphitization could be achieved unless a minimum sulphur content of 0·04% was imposed.

I raise these points as an indication of the remarkable sensitivity to graphitization, possibly related to casting temperature, which low-sulphur materials possess, and herein, I think, is the main link with the authors' present researches.

Co-workers of Morrogh and Williams have shown the effect of sulphide formation and composition on the mode of occurrence of graphite in the malleable irons, and in the manufacture of chilled rolls our researches have shown the importance of sulphur and sulphide shape control on graphitizing phenomena.

I should like to ask the authors whether they consider there is a possibility of one of the sulphur compounds being soluble to a limited extent in iron carbide. If so, it may be that different sulphide compositions have widely differing solubilities in this phase, hence affecting the subsequent graphitization. This is an interesting speculation which may be wide of the mark, but it does appear that sulphur is the fundamental element involved.

A further interesting speculation is on the mode of combination of cerium in Nodulite. Is it possible that the interpretation of Baukloh and Meierling is correct in that the cerium combines initially as a carbide CeC_3 (after sulphur reduction), and subsequently decomposes exothermically into $CeC_2 + C$, the liberated carbon acting as nuclei for spherulitic growth, and that the exothermic decomposition is responsible for the kink in the authors' cooling curve?

Finally, I think this and previous papers by the authors contain much more logical reasoning than the earlier American work of Eash and his contemporaries, and no doubt the work at the B.C.I.R.A. will be extended beyond the present immediate field.

As yet we know little about the effect of slag control on cast iron and as this is obviously related to melting conditions, may I express a hope that we shall have future papers linking up all these factors.

Mr. **C. A. Payne** (Qualcast, Ltd.): One of our difficulties in experimenting with cast iron is our ignorance of the form in which carbon is present in the liquid alloy. There is a possibility that it is just a straightforward solution of carbon in iron, or that it exists entirely as iron carbide dissolved in molten iron. It is quite likely that it is somewhere in between those two, depending upon the temperature, the rate of change of temperature, and the presence of some element which may possibly combine with carbon or have a catalytic influence on the formation or the breakdown of iron carbide. That is pure conjecture, and until we can get some solid experimental evidence it must remain so.

The point being made is that cooling rate or rate of change of temperature can in many circumstances behave like an alloy addition to an iron–carbon alloy. If we add a carbide stabilizer or if we cool extremely rapidly and from a higher temperature we get parallel phenomena—I am not going to say they are identical. Speaking now from experience of a works metallurgist engaged in the manufacture of hyper-eutectic cast irons, it is noticeable that with an undercooled structure

* *Transactions of the American Foundrymen's Association*, 1943, vol. 51, No. 2, p. 261.

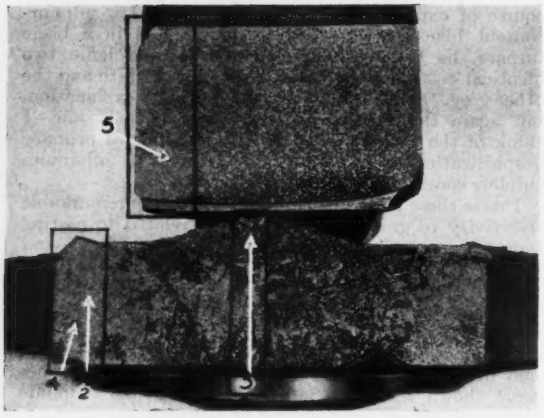


Fig. A—Variation in fracture

obtained by very rapid cooling in a metal mould we get three things: First of all, we can get a tendency to inverse chill, which, by the way, is very marked the more hyper-eutectic we go. With that inverse chill, which has a characteristic acicular structure, we get the presence of tiny spherulites of graphite. Such an occurrence is tied up with a very rapid cooling rate or a very hyper-eutectic iron. Secondly, if the same ladle of iron is held until the temperature has dropped sufficiently and a sample is poured, it is quite likely that with a very hyper-eutectic composition we shall get almost entirely flake graphite, by a cooling rate which is just as rapid, but merely from a lower temperature. Intermediately between these two extremes we can get a chill-free, kish-free, undercooled graphite. We have, therefore, three possibilities from the same ladle of iron, depending upon the initial temperature of pouring.

If we add cerium, which is a carbide stabilizer, and if we cool rapidly following this stabilizing, we get inverse chill with traces of nodular graphite. Is it the rapid cooling which has done the trick, or is the segregation toward the last part to be solidified of minute traces of cerium, or a local undercooling, or, as suggested in the paper, the result of pressure on the normal graphitization?

I should say that it is rather hard to find evidence that pressure will stop graphitization, but the production of undercooled graphite does give rise to very considerable pressure, as evidenced by the exudation on removing the casting too rapidly from the mould. The pressure of graphitization in nodular irons is typified in the paper by a distortion on a small section adequately fed. Is it a gas phenomenon? There is some evidence that if we do not get an inverse chill we may get an internal unsoundness where that inverse chill would have occurred. Do we get the unsoundness because the gas has been liberated, and the chill because the gas is still in combination?

We read that phosphorus puts a limit on the process, and when we reach 0·5% of phosphorus, or something of that order, the cerium addition does not work.

Coming back to the commercial production of undercooled graphite irons, we had occasion some three or four years ago to run into severe trouble with inverse chill with remarkably hyper-eutectic iron of a carbon equivalent of 4·8%, with a low phosphorus (average 0·1% and lower). Since then we have, with 0·5–0·6% phosphorus iron, reproduced a carbon equivalent of 4·8% with no or very little inverse chill. We put that down merely to the effect of phosphorus in widening the range-of-solidification temperature. Is that the way in which phosphorus inhibits the cerium treatment, or have the authors evidence of some combination between phosphorus and cerium which stops the process?

Lastly, referring to Mr. Marles' paper, I know that we are dealing with much more complex material than iron–carbon–silicon alloys, but some years ago, trying heat-tinting on this inverse chill, we got this differentiation, and to my mind it was connected with the fact, rather alarmingly, that the higher we went in silicon the more we were prone to inverse chilling, *i.e.*, the higher above the eutectic. Is it possible to obtain any confirmation of that point, that the higher the eutectic is exceeded by increasing silicon and carbon the greater is the tendency for this unstable silico-carbide phase to separate out, without necessarily resorting to an artificial chill?

In putting these questions to the authors I do not wish to detract from the praise which has already been given to these two admirable papers.

Mr. **R. J. Brown** (Morris Motors, Ltd.): Mr. Morrogh and Mr. Williams are to be congratulated upon the excellence of their further contribution to the study of graphite structures in cast iron. The following comments are not intended in any way as a criticism, but purely as a series of observations upon samples of cupola-melted castings in nodular cast iron, produced by melting hematite pig followed by ladle treatment with soda ash, inoculation with SMZ, and final treatment with cerium in the form of mischmetall. The proportions of the additions are given below:

Addition Agent	Weight per 500 lb.	Weight per lb., g.
Soda ash ...	8 lb.	7·26
SMZ	3½ lb.	3·18
Mischmetall ...	1200 g.	2·4

Castings have been examined from two separate melts, the sulphur content of one of these melts being 0·083% before desulphurization, and 0·032% after soda-ash treatment; after all additions the final sulphur content was between 0·005 and 0·010%, conforming to the authors' requirements of a maximum figure of 0·06% prior to the cerium addition. The chemical composition and the mechanical properties of the castings are as follows:

Chemical Composition

	Sample 1, %	Sample 2, %
Total carbon ...	3·79	3·40
Graphitic carbon	3·76	3·30
Silicon	2·92	2·75
Manganese ...	0·52	1·14
Sulphur	0·006	0·006
Phosphorus ...	0·024	0·018
Zirconium ...	0·043	0·036
Cerium	0·052	0·048

Mechanical Properties

	Sample 1	Sample 2
Effective sections	6 × 1½ in.	6 × 2 in.
Yield point, tons/sq. in. ...	27·76	...
Ult. tens. str., tons/sq. in. ...	33·04	28·56
Elongation, % ...	6	...
Impact strength, ft.lb.	30, 95	52, 52

In their conclusions the authors point out that the problem is to determine the mode of formation as spherules of the hypo-eutectic graphite. Examination of a number of castings provides absolute evidence that for a given composition mass effect plays a large part

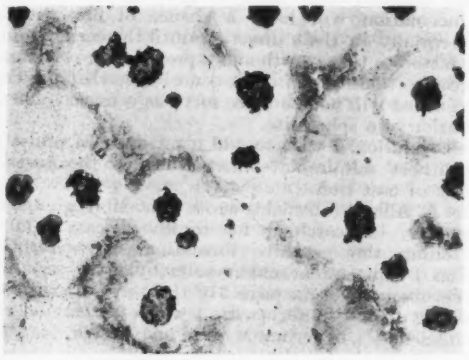


Fig. B—White crystalline zone *(see* area 2 in Fig. A*)* : spherulitic graphite

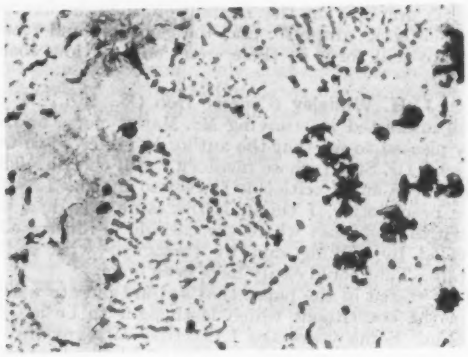


Fig. C—Mottled zone *(see* area 3 in Fig. A*)* : undercooled graphite with partly formed spherules

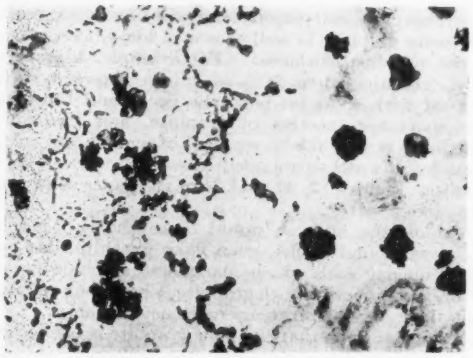


Fig. D—Transition between white and mottled zone *(see* area 4 in Fig. A*)*

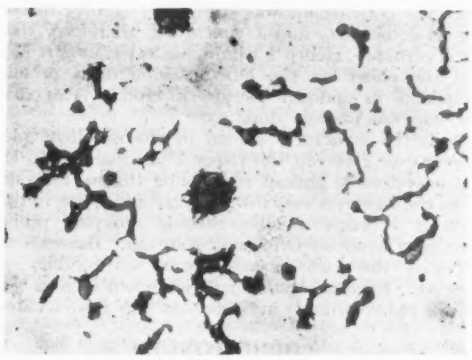


Fig. E—Heavy section *(see* area 5 in Fig. A*)* : spherulitic and quasi-flake graphite

Figs. B to E—Etched with picric acid × 100

in the formation of nodular graphite. With castings of varying sections it is quite usual to obtain a white crystalline fracture in the lighter sections and a partially mottled fracture in the heavier sections (Fig A), although judicious adjustment of the composition of the metal may be successful in producing a white crystalline fracture throughout.

Examination of the microstructure of these varying fractures is of interest, the white crystalline zones generally having the graphite entirely in the spherulitic form (Fig. B), whereas the mottled zones have the graphite in the undercooled form (Fig. C) with isolated patches of partially formed spherules. The interface of the white and mottled zones is of interest (Fig. D), and shows spherulitic graphite in the white zone with partially formed spherules and undercooled graphite in the mottled zone. The casting with the heavier section has a fairly uniform fracture lying midway between the white and mottled condition, and contains graphite in both the spherulitic and the quasi-flake form (Fig. E).

A consideration of these structures, showing graphite ranging in form from undercooled to spherulitic at different locations in a single casting of uniform composition, indicates that cooling rate cannot be dissociated from the formation of spherulitic graphite in cerium-treated cast iron. On page 310 of their paper the authors refer to low cerium content producing undercooled graphite, high cerium content an absence of graphite, but medium cerium content spherulitic graphite, the observations relating solely to a 1·2-in. dia. test-bar. For a given cooling rate, cerium content appears, therefore, to be the controlling factor, but with castings of varying section it is possible that graphite in varying forms must be expected, even though the test-bars of varying diameters referred to by the authors on page 311 all possess structures containing both spherulitic and quasi-flake graphite.

I would suggest that for a given melt of cerium-treated cast iron there is an optimum cooling rate for the formation of spherulitic graphite, and that lower cooling rates will produce quasi-flake graphite, whereas still lower rates produce undercooled graphite. This supports the authors' suggestion on page 316 that decomposition of the carbide to spherulitic graphite is extremely rapid and occurs at high temperature, although it is very doubtful whether the example shown in Fig. 37 illustrates graphite flotation while the metal was still liquid, unless the authors have obtained dissimilar carbon figures for the different zones of the casting.

The formation of nodular graphite is undoubtedly closely related to inoculation, the assistance of the inoculants used in the double-treatment process confirming this view, and it is likely that the authors' concluding suggestion that cerium induces nuclei into the melt which promote spherulitic crystallization of the hypo-eutectic phase, is correct. A further possibility is that quasi-flake graphite is formed by deposition of the

eutectic graphite on the initially formed undercooled hyper-eutectic graphite, and that normal undercooled graphite will form in these irons only at low cooling rates.

Dr. **J. H. Whiteley** (Consett Iron Co., Ltd.): I was much interested in studying Mr. Marles' paper and was very pleased to see that the author has referred to work done by Dr. Stead whose memory I still cherish. There is only one small criticism I wish to make. It would have been better, I think, if the same area had been shown in each case where the carbide is illustrated as revealed by etching and by treatment with sodium picrate. That could easily have been done.

It is stated in the paper that sodium picrate will not stain the constituent which is thought to be a silico-carbide. Some years ago I described a segregate that appeared in a series of bath samples which I had examined for the Ingot Committee.* In the segregate there was usually a white constituent which looked like cementite, but it was not stained by boiling sodium picrate. When the specimens were held for 2 hr. in that reagent at about 20° C. the constituent was stained in exactly the same way as cementite, and I concluded, therefore, that it was a carbide. Hence I would suggest that Mr. Marles tries the effect on the silico-carbide of a prolonged immersion in sodium picrate at room temperature, if he has not already done so.

From the structures shown in the excellent photo-micrographs given in the paper I am inclined to think that a system is present resembling that of FeS–MnS.† When the silicon is very low, iron carbide is precipitated; when it is high a silico-carbide appears, probably containing some Fe_3C in solid solution. Between these extremes the two phases, being immiscible, occur together. Further, the structures shown in Figs. 8 and 9 of the paper strongly indicate that they form a eutectic.

CORRESPONDENCE

Mr. **Axel Hultgren** (Royal Institute of Technology, Stockholm) wrote: In making the following comments on the paper by Morrogh and Williams I shall assume that the graphite, when formed under the conditions defined by the authors, is precipitated from the melt.

It appears likely that an addition of cerium acts in two ways: (1) The nucleation of graphite is delayed or hindered, and (2) if and when graphite nuclei form they grow preferentially in the direction of the *c* axis. If this is true the so-called quasi-flake graphite should have the shape of rods, probably irregular, perhaps tapered. By some unknown mechanism a group of such nuclei will grow into a spherulite if certain conditions are fulfilled, in this case, if the cerium content in the melt is suitable and sufficient.

Inoculation may be assumed to promote nucleation of graphite without affecting its manner of growth, *i.e.*, the nuclei will generally grow preferentially in the *a* directions, *i.e.*, develop into flakes.

Thus, if a suitable amount of cerium is first added to a hyper-eutectic iron and given time to dissolve, and the melt is then inoculated without delay, nuclei are presumably not formed until inoculation occurs. The presence of cerium in the melt will cause the nuclei to grow into spherulites. The eutectic graphite will tend to grow upon the existing hyper-eutectic nodules, the eutectic austenite at the same time being precipitated at some distance.

If, on the other hand, the melt is first inoculated and cerium is added afterwards, the graphite nuclei formed on inoculation will have a chance of first growing preferentially in the *a* direction until the cerium added puts a stop to this growth and a preferred growth in the *c* direction takes place. It is conceivable that the flake first formed will not be fit to serve as a nucleus for the formation of a spherulite.

In conclusion, I wish to add my tribute of praise for the authors' admirable contributions to the metallography of cast iron.

Mr. **A. Allison** (Sheffield) wrote: Mr. Morrogh and his colleagues, in searching for improved cast iron by controlling the graphite formation, have certainly produced some remarkable results by using cerium.

The observation on page 310 that an iron with 4% of silicon should solidify with a white fracture on containing 0·034% of cerium is quite unexpected.

For convenience the authors distinguish between flake graphite, undercooled, and nodular graphite, but I would suggest a further variety, rosette graphite, not to be confused with their quasi-flake graphite. Undercooled graphite is not a happy expression and the present researches give good reasons for modifying the expression.

Rosette graphite is well shown in low-silicon castings on the machined surfaces. For example, a grain roll which contains about 1% of silicon shows a surface dappled with spots on both the necks and the barrel. The spots are rosettes of graphite, and incidentally contribute largely to the removal of scale in hot rolling, being softer areas surrounded by a mesh-work of harder pearlite. Figures 17, 20, and 24 of the paper show something like rosettes.

I think the authors would agree that all graphite is formed round nuclei, even flake graphite, and from the frequency with which manganese sulphide crystals occur in conjunction with graphite, I have long suspected that these crystals in many cases act as nuclei.

I would suggest that the flake graphite is one extreme form and nodular graphite the opposite extreme; and that flake graphite is formed with great rapidity and nodular graphite slowly, as, for example, in malleable cast iron. In Fig. 21 of the paper quasi-flake graphite is shown to be an aggregate of nodules.

The effect of a carbide stabilizer—not a very exact expression—is to delay the decomposition of the primary carbide; it is a question of time, which may explain the imperfect nodules described.

Since sulphur delays the decomposition to some extent and cerium to a remarkable extent, this raises the question whether or not the carbide is as pure as we thought it should be.

The carbide has always been considered to be a double carbide containing manganese and the small amount of chromium frequently present. The paper seems to suggest that cerium enters into combination in some way to delay decomposition. Evidently the authors have considered this, and Mr. Marles' paper sheds some light on the matter. Heat-tinting has been tried to produce differential effects. I would ask if boiling sodium picrate for a considerable time has been tried, because I have obtained remarkable colour effects on the carbide which give beautiful colour photographs, though with a much narrower range of alloys.

Silicon is known to be the dominating element in producing white or grey fractures, apparently by forming a highly metastable carbide, and lowering the solubility of carbon in iron. Nickel, besides producing sluggishness of reaction in all ferrous products, reduces the solubility of carbon, having about one-third of the efficiency of silicon in that direction.

Some measure of the relative powers of silicon and cerium is given on page 318, where 10% of silicon by

* *The Iron and Steel Institute*, 1937, *Special Report No.* 16, Figs. 70 and 71.

† *Ibid.*, Fig. 83.

mass action largely balances the somewhat high cerium contents.

With regard to phosphorus, the results are quite consistent with its known property of reducing the solubility of carbon in iron. In white iron patches of eutectic associated with carbide may frequently be seen.

The double-treatment experiments seem to show that the number of nuclei has an important bearing, the nuclei probably acting as irritants or additional chemical reagents, accelerating the somewhat sluggish decomposition. In any case, we are considering a rapid physical action together with chemical segregation.

The two papers provide evidence that primary carbide is of very indefinite composition, liable to decompose very rapidly or more slowly according to composition, and that cerium has very powerful effects in delaying decomposition, overriding silicon, nickel, copper, etc., in the opposite direction.

In this complicated study the authors are to be congratulated on having at least found a clue in their search for means of controlling graphite formation, and again on the excellent photomicrographs.

AUTHORS' REPLIES

Mr. **W. J. Williams,** in reply, said : I was particularly interested in the announcement made by Dr. Pfeil to the effect that they had succeeded in producing nodular irons by means of the introduction of magnesium into the melt. The staff of the International Nickel Company are to be congratulated upon this development. Dr. Pfeil did not give any details, but one point struck me, namely, the statement that the introduction of magnesium first has a desulphurizing effect, and then produces quasi-flake graphite, and then nodular graphite. If the mechanism of formation of these structures by means of the introduction of magnesium is the same as that which we have found with the addition of cerium, I wonder whether any carbides are formed with an excess of magnesium. We shall look forward with very great interest to further information upon this process.

The questions asked by Mr. Hallett, Mr. Payne, and Mr. Wright, are mainly technical questions dealing with the fundamental mechanism of formation of quasi-flake and nodular graphite structures. We have gone into this subject in considerable detail and carried out numerous experiments to try to elucidate the problem. The paper which we have contributed to the *Journal*, however, is an attempt to give an explanation for the production of these structures on the basis of the facts as they are available at the moment. Mr. Hallett has pointed to the fact that even with very small additions of mischmetall, quasi-flake and nodular structures could be formed in rapidly cooled castings. In this connection I would add that nodular structures can be produced on a small scale merely by the rapid cooling of small specimens immediately solidification is complete, even when such metal has not been treated with cerium. The mechanism of solidification of these irons is obviously a complex process and it is not possible to reply to all the points which have been raised without further consideration; I will therefore endeavour to reply in greater detail in writing.

Mr. **H. Morrogh** and Mr. **W. J. Williams** wrote in reply : Dealing with the announcement made by Dr. Pfeil that a process had been developed by which nodular structures were produced by the addition of magnesium to cast iron, it will be apparent from our previous paper* that the use of magnesium in this connection was likely to be a possibility and, in fact, some nodular structures have been produced in cast irons by the appropriate addition of magnesium, thus confirming the findings of the International Nickel Company, but no satisfactory process had been developed for application in the foundry.

In reply to the points raised by Mr. Hallett, it is interesting to note the differences which he observed between sand-cast cerium-treated metal and centrifugally cast cerium-treated metal. In this connection, it is relevant to point out that even in the sand-cast bar treated with the largest amount of mischmetall in his experiment we have a case of the production of a nodular structure with a very small addition, and furthermore, centrifugal casting itself is not a straightforward case of rapid cooling ; it may involve various segregation effects. The paper confirms that quasi-flake graphite itself is associated with good mechanical properties, but we feel that even in the case of the centrifugal casting the mechanical properties would be better with an entirely nodular structure. As Mr. Hallett has pointed out, this is complicated in his case by the presence of some massive carbide. It is probably true that the improved mechanical properties associated with the quasi-flake graphite are in some way connected with the modification of the points of stress concentration due to the shape of the quasi-flake graphite, but it is also worth noting that comparing an untreated flake-graphite iron with one containing quasi-flake graphite, there appears to be much less graphite in the latter iron. This could probably indicate that in the case of quasi-flake graphite and, incidentally, also in the case of nodular graphite, that the mass/surface-area ratio is much higher than is the case for flake graphite since the chemical analyses reveal the same graphitic-carbon content. Quasi-flake graphite structures do not appear to offer the same continuity for the path of fracture as do flake-graphite structures.

The points raised by Mr. Hallett, in connection with the apparently high percentage of ferrite in cerium-treated irons having quasi-flake or nodular graphite structures, are extremely interesting, but it is worth while to bear in mind that the difference in amount of ferrite between these and flake-graphite irons may be only apparent, since combined-carbon determinations available at the moment do not confirm that there is more ferrite in the cerium-treated irons. Undoubtedly the distribution of the ferrite around the nodules is a subject for further investigation. Mr. Hallett refers to the impoverishment of the austenite in carbon arising from the complete precipitation of the carbon in the carbide eutectic. This may be the case, but as yet there is no information to substantiate this view and it is highly probable that the decomposition of iron carbide at elevated temperatures occurs with the formation of saturated austenite and graphite.

The questions raised by Mr. Wright are most interesting and are extremely relevant to the whole of the ironfounding industry. Anomalous structures which are apparently independent of known chemical analyses are continuously being observed by workers in this field. Ultimately we hope that complete answers to these questions will be forthcoming and perhaps, as Mr. Wright implies, the present work may help to throw some light on these phenomena. The theory that cerium carbide could occur in cast irons and could break down to give graphite nuclei is a remote possibility which must be borne in mind, but we have no evidence either to substantiate or to refute it. In this context it should be remembered that theoretical considerations would suggest the austenite originating at the hypertectic transforma-

* *Journal of The Iron and Steel Institute*, 1947, vol. 155, Mar., p. 321.

tion to be richer in carbon than normal eutectic austenite. If this is borne in mind, then one must remember that this supersaturated austenite may give rise to graphite nuclei. However, the only positive and recurring evidence of the inoculating action of graphite nuclei is that of the hyper-eutectic nodules which repeatedly show a secondary deposition of graphite, as is, for instance, illustrated in Figs. 22 and 35 of our paper.

In general, the points raised by Mr. Payne are similar to the anomalies referred to by Mr. Wright. We are in agreement with Mr. Payne's observation of the interrelation of rate of cooling and the influence of alloying elements. This was clearly demonstrated in the earlier work upon the nickel–carbon alloys, when undercooling to give nodular structures could be produced either by the addition of an appropriate alloying element or by relatively rapid cooling, provided that the alloys were low in sulphur. In view of the analogies existing between iron–carbon–silicon alloys on the one hand, and nickel–carbon alloys on the other, it is reasonable to suppose that just as is the case with nickel–carbon alloys, undercooling to give nodular structures could be produced in rion–carbon–silicon alloys by either the addition of an appropriate element or by rapid cooling. The present paper confirms the first possibility and, as has already been mentioned in Mr. Williams' reply, it has been found possible to produce some nodular structures by the appropriate rapid cooling of cast irons of hyper-eutectic composition similar to those described in the paper, but not containing cerium. However, in this connection it should be emphasized that from a practical point of view at the moment, irrespective of the rate of cooling, it seems necessary that in cerium-treated irons at least 0·02% of this element and not more than 0·02% of sulphur should be present. This is purely a practical recommendation and no doubt nodular structures can be obtained outside these limits.

Mr. Payne asks whether the effect of phosphorus in inhibiting the cerium treatment is due to the effect of phosphorus in widening the range of solidification temperature. We have found that increasing phosphorus progressively reduced the solubility of cerium in the melt so that with more than 0·5% of phosphorus it is not possible under ordinary conditions to obtain sufficient cerium in solution to effect the change in graphite structure.

Mr. Brown's contribution deals more directly with the commercial production of cerium-treated nodular irons. He gives the order of addition in his experiments as SMZ, followed by cerium, whereas the order recommended by us is that of cerium followed by the inoculant. Section size naturally influences the structure, particularly as the hyper-eutectic graphite nodules are subject to flotation in heavy sections during cooling. In addition, in such heavy sections they tend to be coarser and result in larger volumes of metal free from their potential inoculating action, thus tending to give rise to the formation of quasi-flake graphite rather than nodular graphite.

Mr. Brown gives an example of what he calls " graphite in the undercooled form " (Fig. C) and later refers to our reference on page 310 to undercooled graphite produced by cerium additions. Care must be taken not to confuse these two forms of graphite. Both types tend to follow a similar general distribution, but the individual particles of graphite in the two forms are quite different when examined closely at high magnifications. The mechanical properties of cerium-treated irons with the " undercooled " type of graphite shown in Fig. C are superior to the mechanical properties of an iron with the ordinary undercooled form of graphite.

The authors agree with Mr. Brown that there is an optimum cooling rate for the formation of entirely spherulitic graphite structures and that, for reasons given above, lower cooling rates tend to produce quasi-flake graphite, but they are unable to agree that still lower cooling rates produce undercooled graphite. It is only the hyper-eutectic graphite that forms as spherulitic nodules. If there is a uniform distribution of these nodules and if they are satisfactorily evenly dispersed so that their spheres of influence overlap, the eutectic graphite forms around them as a secondary deposit, as has been illustrated. In the absence of hyper-eutectic nodules owing to low total carbon or flotation due to slow cooling, or centrifuging action, the eutectic graphite, depending on the rate of cooling and cerium content, may form either as quasi-flake or as the " undercooled " form shown in Fig. C of Mr. Brown's contribution. Only when the cerium content is so low that it fails to influence the structure of the hyper-eutectic graphite will the normal undercooled form of graphite occur.

We feel that there is no doubt whatsoever that Fig. 37 illustrates segregation of hyper-eutectic graphite nodules, and similar segregations have been observed in the top parts of heavy-section castings made in stationary sand moulds. That a segregation of graphite does occur has been confirmed by chemical analysis.

Finally, in reply to Mr. Brown, the authors have not yet observed undercooled hyper-eutectic graphite of such a form that could give rise to quasi-flake graphite. Quasi-flake graphite can occur in hypo- as well as in hyper-eutectic irons. Again, we wish to emphasize that we feel Mr. Brown is confusing what he calls " normal undercooled graphite " with the structure he gives in Fig. C when dealing with slow rates of cooling.

Mr. Hultgren raises some pertinent points with respect to the manner of graphite crystallization. For no very obvious reason he has assumed that all the graphite is precipitated from the melt, whereas the authors have demonstrated that apart from the hyper-eutectic nodules it is most likely that all the other graphite arises from carbide decomposition after solidification. Normally hyper-eutectic flake-graphite crystallites grow in directions at right-angles to the *c* axis, whereas spherulitic crystallization proceeds largely in the direction of the *c* axis. Obviously, then, the cerium addition is responsible in some way for this change in the direction of crystal growth, but, as has been pointed out in the papers, although hyper-eutectic spherulites appear while the metal is still molten, we are not satisfied that we can claim that the spherulitic structure forms directly from the melt. It still must be borne in mind that it may form *via* a carbide phase.

Mr. Allison suggests an expansion of the present nomenclature for graphite formations. At the present time this is well justified, but the authors are not satisfied that rosette graphite should be distinguished from flake graphite and undercooled graphite in the manner that he suggests. Rosette graphite represents a combination of undercooled graphite and flake graphite. Any further classification must obviously take into account the manner in which the graphite has formed, that is, whether it is flake or undercooled and the manner in which these structures may be combined together. The authors cannot agree that all graphite is formed around nuclei. There is as yet no concrete proof of the existence of these nuclei.

Mr. **D. Marles** replied : In reply to Mr. Owen, I have not been able as yet to fit a new carbide phase into the ternary iron–carbon–silicon system. We have attempted X-ray examination, the carbides being separated from the metal by means of cold 10% hydrochloric acid,

but it is possible that at the higher silicon levels some decomposition of the carbide took place and the results of the X-ray examination were not instructive.

I was interested in Mr. Owen's attempt to introduce the concept of an equilibrium diagram in the explanation for the two carbide phases which have been observed in the iron–carbon–silicon system. In dealing with this point I should like first of all to emphasize that the alloys which were used in this investigation were not cooled under equilibrium conditions. The paper states clearly that they were rapidly cooled in chill moulds. We know that such alloys, if cooled slowly under equilibrium conditions, would have quite different structures, that is, they would be grey irons having none of the massive carbide phase. If this point is appreciated the difficulties inherent in attempting to explain the structures in terms of equilibrium diagrams will be readily seen.

In his third paragraph Mr. Owen assumes that the two carbide phases separate directly from the liquid. No such assumption has been made by the author, since at the present stage of our knowledge it is obvious that one must take into consideration the possibility that these two phases originate because of some transformation occurring after solidification. If this should in fact be the case it would account for previous workers having found no indication of an invariant point in their thermal analyses. However, thermal analysis by itself is not entirely satisfactory and several transformations in the iron–carbon–silicon system are known which are not apparent by thermal analysis.

It is interesting that Mr. Owen should suggest that the two phases observed represent a segregation effect, but this would seem improbable when the boundary lines between the two phases are so clearly delineated and when the two phases on frequent occasions occur as alternating parallel lamellae, apparently bearing some crystallographic relationship to each other. It is agreed that much further work remains to be done on the carbide phases in cast iron, and with this in mind I have made no attempt to evolve a very fundamental interpretation of the results available.

Mr. Payne raised a point with regard to inverse chill. I cannot say from my experience whether silicon increases or decreases the tendency for its formation. However, Hurst and Riley have commented upon the apparently surprising stability of the carbide phase in high-silicon acid-resisting cast irons.

In reply to Dr. Whiteley, we have tried boiling alkaline sodium picrate, but did not obtain any differentiation between the two carbides. We have not tried cold sodium picrate solution.

Joint Discussion on the Papers—

A MICRO-EXAMINATION OF EIGHT STEELS FOR THE INCLUSIONS SUB-COMMITTEE* *by J. H. Whiteley*

THE STUDY OF SEGREGATIONS AND INCLUSIONS IN STEEL BY MICRO-RADIOGRAPHY† *by W. Betteridge and R. S. Sharpe*

SOME THERMODYNAMICAL ASPECTS OF THE FORMATION OF INCLUSIONS IN MILD-STEEL WELD METAL‡ *by E. C. Rollason and E. Bishop*

Dr. **W. Betteridge** presented the paper by himself and Mr. R. S. Sharpe.

Dr. **J. H. Whiteley** presented his paper.

Mr. **E. Bishop**, in presenting the paper by Dr. Rollason and himself, drew attention to an error in the paper as printed in the *Journal*. On page 166, second column, in the first two lines under Table VI, the sentence should read: "MnO varies from 0·09% to 0·18%".

Mr. **H. H. Burton** (English Steel Corporation, Ltd., Sheffield): I am in rather a peculiar position in opening the discussion, because I happen to be Chairman of the Inclusions Sub-Committee, to which Dr. Whiteley was somewhat unkind in suggesting that its report would be published sometime in this century. I think that in fairness, and also by way of explanation as to why some of these investigations were started, I should say that we began in order to prove or disprove the existence of what have come to be known as "harmful inclusions." If you merely talk of "non-metallic inclusions" or "inclusions" and do not preface those terms with the adjective "harmful" you get an entirely different picture, but many users of steel over a period of years—perhaps it is dying out a little—have come to regard any sort of non-metallic inclusion, however minute, as essentially harmful. The Inclusions Sub-Committee, therefore, set out to discover which, if any, of the inclusions were harmful, either in type or in number.

I am sure that Dr. Whiteley, who is a member of the Sub-Committee, will agree with me that in spite of the fact that the report is a long time in appearing a vast amount of work has been done. We are much indebted to the Bristol Aeroplane Co., Ltd., for the work they have done, which has included fatigue testing on a scale almost undreamt of. The effect of the work will be to relieve the minds of many people—not only users, but manufacturers of steel—as to the so-called harmful effect of many inclusions. At the same time, we are still rather in the position of the bishop who gave a definition of an archdeacon, and if we were asked now: "What is a harmful inclusion?" we should have to say, in all honesty: "One which exercises a harmful influence."

To turn first to Dr. Whiteley's paper; I think that anyone who has read it will realize what an immense amount of careful work he has put into this. It is in a sense unfortunate, in view of his beautiful pictures of

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Sept., pp. 89–97.

† *Ibid.*, 1948, vol. 158, Feb., pp. 185–191.

‡ *Ibid.*, 1948, vol. 158, Feb., pp. 161–168.

the inclusions, that side by side with them we have not yet got the fatigue results on this same group of steels. I am not prepared to say that even if we had we should always find that they would come out according to what we would suppose from the pictures, because in certain respects the steel which is obviously the cleanest has not always turned out to be the best under all conditions of fatigue testing. Nevertheless I feel that the value of this paper will be fully appreciated only when the report on the other work appears, at some later date. There are two interim contributions on these lines already with The Iron and Steel Institute.

The paper by Betteridge and Sharpe, although it was started perhaps from quite a different angle and not in conjunction with the Inclusions Sub-Committee, seems to me to be almost complementary with and supplementary to that of Dr. Whiteley. I am not very familiar with this technique myself, but it seems to me from what I see here that it is likely to be very valuable. If you look at the pictures of some of these inclusions, for example for the ball-race steel, you will see how much more there appears to be associated with the inclusions than in some cases the ordinary micrographic technique would show. The thought occurs to me that perhaps the fatigue results which are reported to the Inclusions Sub-Committee, and which do not always line up with the normal metallographic examination, might do so rather better if the micrographic technique were supplemented by this micro-radiography. The method of polishing the specimens adopted by the authors seems to be very effective and well worth noting.

The third paper, by Rollason and Bishop, is rather more out of my province than the other two. Perhaps I am one of those who regard weld metal with some misgivings. It is very gratifying to find that the evidence put forward here is so strongly in favour of the idea that in the formation of inclusions in weld metal equilibrium conditions are reached. I should like to ask a question about one point arising out of this paper which did not seem to me to be clear. What was the technique adopted in obtaining these samples of weld metals ? Were they just obtained by fusing two rods of weld metal together by striking an arc between them, so to speak, or were they obtained on an actual welding run ? If the latter, it is likely to be difficult to say which part of the weld run is representative, and surely the parent metal must come into it a good deal. Nevertheless this seems to me to be a most interesting contribution ; it may be that if it is possible, by studying weld metal, to predict accurately in this way what the inclusions will be with a certain type of slag, it may be possible to reverse the process and decide what type of slag it is necessary to have to form certain inclusions, and that might help us in many other directions.

Dr. **F. W. Jones** (Brown-Firth Research Laboratories, Sheffield) : I propose to confine my remarks to the paper by Betteridge and Sharpe. In the Brown-Firth Research Laboratories we started investigating the possibility of studying segregation in steels by micro-radiography round about a year ago. Although the principles of the method were quite clear, we ran into certain difficulties with the experimental technique. I then heard that these authors were using the method very successfully ; I went to Bristol to see them, and they kindly gave me full details about their experimental technique. By the use of their methods we were able to get over our troubles. I think that we should probably have overcome most of those troubles by the rather slow process of trial and error, but the fact that the authors gave us the benefit of their experience did save us very considerable time.

One or two of the details of the technique are by no means obvious. For example, to the X-ray crystallographer the use of relatively low voltages for exciting X-rays would appear at first sight to be rather ridiculous, but our experience confirms that of the authors in that such low voltages are beneficial for obtaining maximum contrast.

The authors have demonstrated that the method may be used for studying segregation in steels, and we feel that their paper will be very useful to anyone who is starting on the problem or who is already engaged on work of a similar nature.

Most of the work that we have done in Sheffield has been on rather high-alloy steels—corrosion- or heat-resisting steels—and it may be of interest to show the type of results which we have obtained.

Figure A shows a highly alloyed steel, with segregation (actually of columbium) in the grain boundaries. Figure B consists of one photomicrograph and two X-ray micro-radiographs with cobalt and manganese radiation, and shows the growth of the sigma phase in the grain boundaries. The heavy absorption of the grain-boundary material when using cobalt X-radiation and the fact that the grain boundaries do not show up with manganese radiation indicate that the sigma phase is rich in chromium. Figure C shows regions of ferrite in an 18% chromium, 10% nickel steel, and again the argument is the same as in the case of Fig. B, namely, that the X-ray micro-radiographs show that the ferrite regions are rich in chromium. In the micro-radiograph with chromium radiation the small white dots are titanium carbide, titanium having a heavy absorption for chromium radiation.

This method is therefore quite useful for giving qualitative information about the compositions of different phases present in complex steels. We came across one limitation of the method, namely that with a fine-grain steel it would be necessary to magnify the micro-radiographs very much more, which would be impossible on account of the grain-size of the film used. At first sight, therefore, it would seem that if you could obtain a finer-grain X-ray film you ought to be able to distinguish between the compositions of different phases in a fine-grain steel, but a little further consideration shows that to obtain resolution with a fine-grain steel you would have to decrease the thickness of your steel specimen to the same order as the grain-size.

Figure E may make the matter clearer. On the left is shown a steel specimen about 0·001–0·002 in. in thickness with coarse grains of a second, heavily absorbing phase. When X-rays are passed through the sample, each grain of the heavily absorbing phase will cast its " shadow " on the film. With the finer-grain material shown on the right, however, you will get a general grey patch on the film, owing to the averaging-out of the large number of grains of this particular phase over the specimen. From this it seems that there is a limitation of the method, in that the smallest grain-size steel in which we are likely to be able to distinguish between the compositions of different phases present is probably

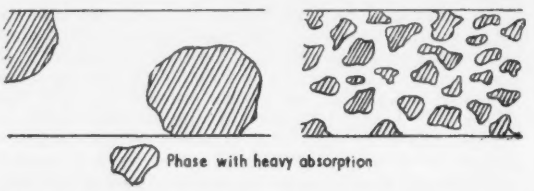
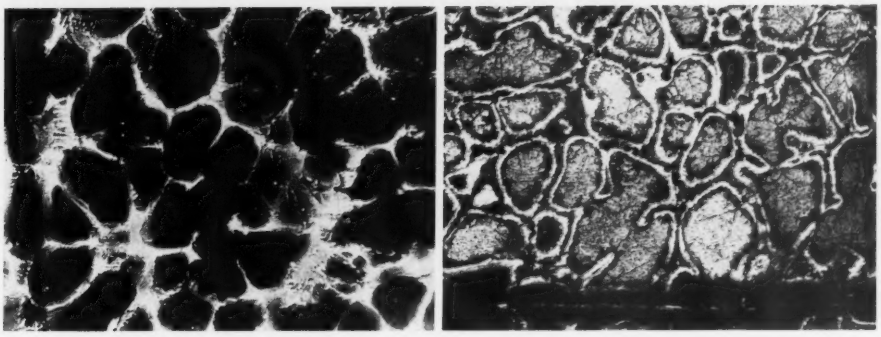
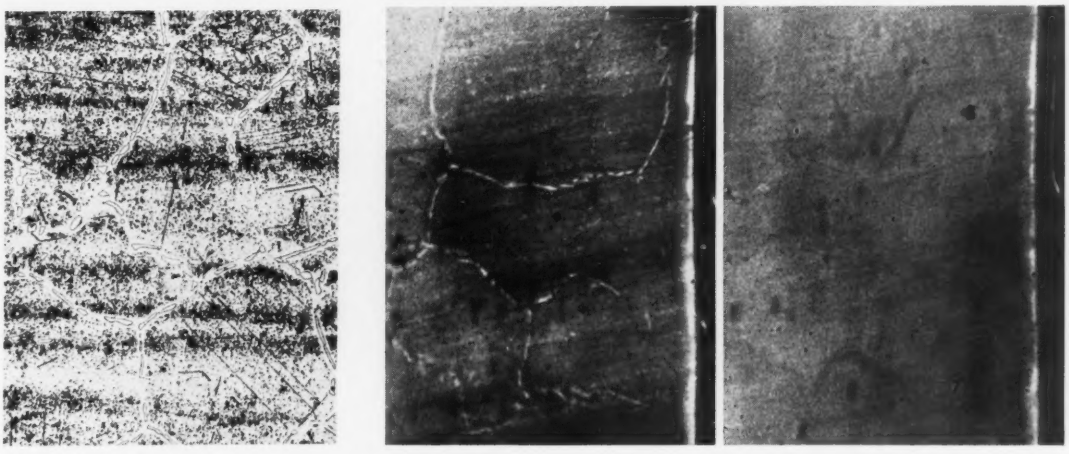


Fig. E—Limiting resolution in micro-radiographs



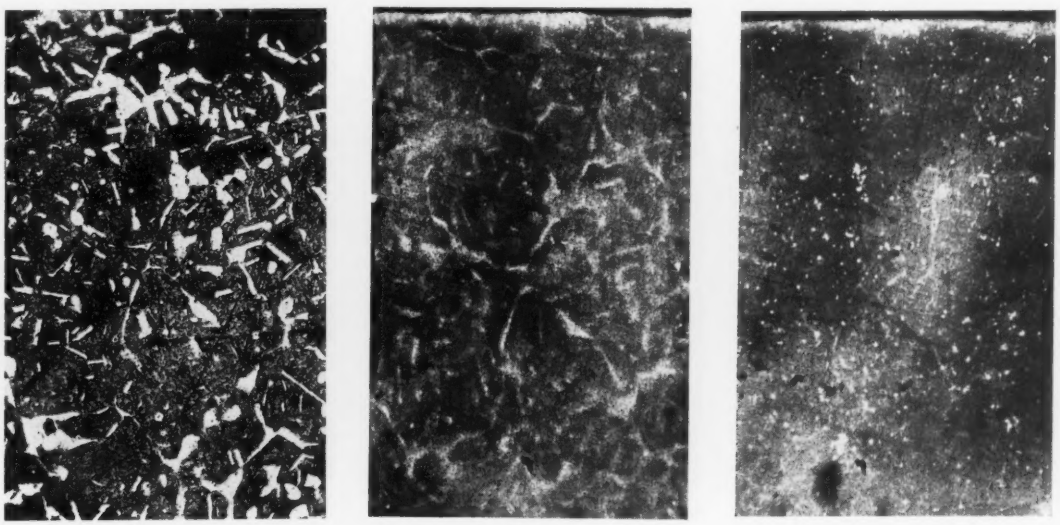
(a) (b)

Fig. A—Grain-boundary segregation of columbium ; (a) chromium radiation ; (b) photomicrograph × 100



(a) (b) (c)

Fig. B—Sigma phase in 25% chromium, 20% nickel steel ; (a) photomicrograph ; (b) micro-radiograph (cobalt radiation) ; (c) micro-radiograph (manganese radiation) × 200



(a) (b) (c)

Fig. C—Chromium-rich delta ferrite in high-nickel F.D.P. (a) Photomicrograph, (b) micro-radiograph (iron radiation), (c) micro-radiograph (chromium radiation) × 200

Figs. A-C reduced to one-half linear in reproduction

[*Discussion on Betteridge and Sharpe*
[*To face p* 30

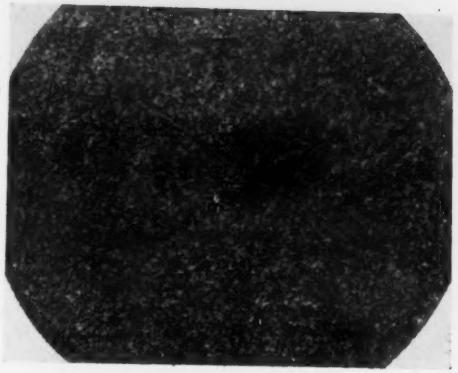


Fig. D (a)—Microstructure of nickel–chromium steel (EN 23), oil hardened at 830° C., tempered for 1 hr. at 650° C., (oil quench), and tempered for 1 hr. at 625° C. (oil quench) × 150

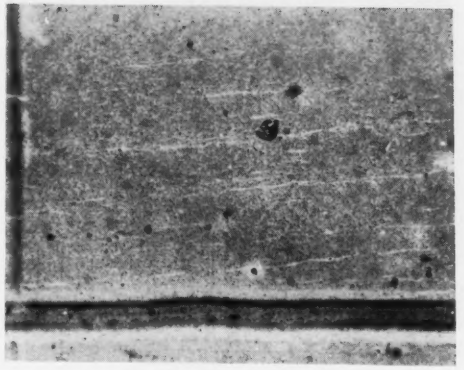


Fig. D (b)—Tempered at 650° C. for 1 hr. (oil quench)

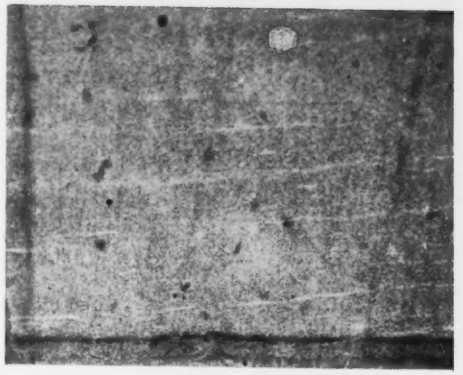


Fig. D (c)—Tempered at 650° C. for 1 hr. (oil quench), followed by further tempering at 625° C. for 1 hr. (oil quench)

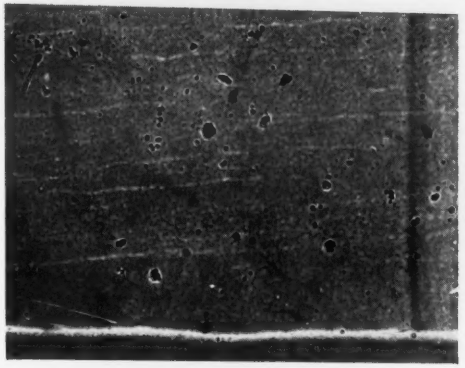


Fig. D (d)—As for Fig. D (b)

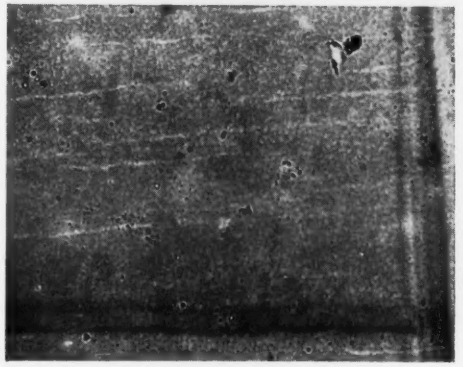


Fig. D (e)—As for Fig. D (c)

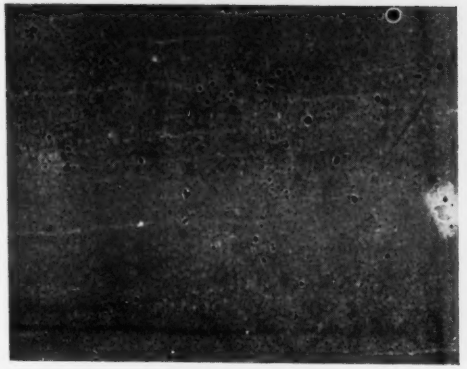


Fig. D (f)—As for Fig. D (c) but with third tempering at 625° C. for 24 hr. (oil quench)

Fig. D (b-e)—Micro-radiographs of nickel–chromium steel (EN 23) after various tempering treatments. Hardened at 830° C. in oil. Cobalt radiations × 150

round about 0·001 in., which with present methods is the thinnest specimen that we can conveniently make.

Mr. **K. J. B. Wolfe** (B.S.A. Tools, Ltd., Birmingham): I should like to congratulate Dr. Betteridge and Mr. Sharpe on providing such an interesting paper on a subject of increasing importance. There can be no doubt that micro-radiography has been shown to be a very successful method of approach to certain metallurgical problems.

It has been most gratifying to learn that the results which have been obtained in the B.S.A. Group Machinability Research Laboratories have been confirmed in every respect in this paper. However, in these laboratories the technique of micro-radiography has been used in a further effort to elucidate some of the problems associated with the effect of heat-treatment on the true machinability of steel, especially under conditions of intermittent cutting. The true machinability of a steel may be described as "that complex property that controls the facility with which it can be cut to the size, shape, and surface finish required commercially."

Recent work on this subject has shown that the true machinability of hardened and tempered constructional steels, especially under conditions of intermittent cutting, such as shaping, planing, and milling, is greatly influenced by the tempering process. It has been found that if a second temper is employed at a temperature approximately 25° C. below that of the first, and this is followed by an oil quench, then the true machinability index of the steel will be greatly improved, although the usual mechanical properties are substantially unaffected. Small variations have been noted in the microstructure, magnetic properties, Meyer analysis values, and also in other properties following this treatment, but not, apparently, of sufficient magnitude to explain completely the differences in the true machinability values which have been experienced. In the case of gear generation by the shaping method, improvements of up to 1000% have been encountered by these means when cutting hardened and tempered nickel–chromium steel (En 23) in the 65-ton condition (Brinell hardness number 270–280). The mechanical properties of this steel after single and double tempering (tempered each time for 1 hr. at temperature and oil quenched) are shown below, and it will be seen that there has been no significant change in these properties :

Property	Oil Hardened 830° C. Single Temper 650° C.	Oil Hardened 830° C. Double Temper 650–625° C.
Ultimate stress, tons/sq.in	59·0	61·0
Elongation on 2 in., % ...	27·5	25
Reduction of area, % ...	40·0	35·0
Izod impact value, ft.lb.	86	93
Vickers pyramid hardness at 30 kg. load	269	281

Figure D (*a*) shows a longitudinal microstructure of this steel. It will be noted that there are no apparent signs of abnormal segregation or non-metallic inclusions. The examination of this steel by micro-radiography, however, indicated that manganese showed signs of severe segregation. A preliminary examination also indicated that these manganese-rich areas apparently tended to disperse during the second tempering treatment. To ascertain whether this was the case, samples, oil hardened from 830° C. and tempered for 1 hr. at 650° C. and oil quenched, were prepared, reference lines scribed on them, and micro-radiographs of the reference areas obtained. The samples were then sealed in evacuated glass tubes and tempered at 625° C. for 1 hr. and then oil quenched. The same areas of the samples were then again radiographed. These areas are shown in Fig. D (*b*) and (*c*) and it can be seen that the double-tempering treatment has caused the manganese segregates to become less sharply defined.

Following the authors' statement that these manganese-rich areas "are not easily diffused into uniform distribution" the sample shown in Fig. D (*d*) and (*e*) was again tempered, this time for 24 hr. at 625° C. *in vacuo*, and then oil quenched. The resulting structure is shown in Fig. D (*f*), and it can be seen that diffusion of these areas is nearly complete.

It is difficult to accept the authors' hypothesis that these areas may be separate phases, as it has not been possible to detect any evidence of this by X-ray diffraction methods, using both powder and glancing-angle techniques. There is no doubt, however, that these areas will have very different properties from the normal steel matrix. This is due to the fact that concentrations of manganese slightly above normal for constructional steels will affect their mechanical properties in a very profound manner. It can therefore be seen that these areas, which must be in the limits of 1–12% of manganese if no austenite is to be present, will be in the form of hard elongated stringers, and consequently they will act during the machining operation in a similar manner to non-metallic inclusions in a free-machining steel. The effect of these areas will be especially heightened if their manganese content lies in the range 5–12%, as steels within these limits are essentially martensitic and consequently very hard and brittle. Owing to their extreme hardness they will, however, like alumina, act as abrasives, and so cause the cutting tool to wear in a very marked manner.

It is therefore reasonable to assume that the effect of the double-tempering treatment on these manganese-rich inclusions is to cause them to disperse and so to become less hard and consequently less abrasive. This will cause less wear on the cutting tool, but will still permit these areas to act in a similar manner to non-metallic inclusions in a free-cutting steel.

It is hoped to publish further work on this aspect of the subject in the near future, because there is no doubt that metallic segregation, especially that associated with manganese, has a great effect on the physical properties of steels. No doubt when its effect has been fully studied several apparent anomalies and inexplicable service failures will be completely cleared up.

Mr. **H. A. Sloman** (National Physical Laboratory, Teddington): I propose to confine my remarks to the paper by Rollason and Bishop. I have read this paper with very great interest, and I should like to congratulate the authors on a most courageous attempt to predict the amounts and identities of the inclusions in weld metal by the use of thermodynamical data. I must confess, however, that they have not convinced me that they have succeeded in what they set out to do. The conclusion to which I have come after a careful study of the paper is that either, despite the excellent work of such well-known thermodynamicians as Chipman and others, our present thermodynamical data are so inaccurate that they cannot be applied to a problem of this nature, or, alternatively, that, contrary to the authors' view, weld metal is so far from true equilibrium that thermodynamical calculations cannot be expected to give an accurate picture of the amounts and compositions of the inclusions in such material.

I am not at all sure that the authors have made the best of their suggested method. Owing to the necessity for simplifying the very complex mathematics involved they have considered only the equilibria between five elements, namely, iron, manganese, silicon, oxygen, and sulphur. I agree wholeheartedly that there are many other elements in weld metal which can legitimately be ignored, but in my opinion the authors have quite

Fig. F—Inclusions in weld (electrode *C*). Unetched × 1500

unjustifiably omitted to consider the effect of hydrogen and carbon. We all know that the gaseous envelope in which weld metal is deposited contains large amounts of both hydrogen and carbon—usually in the form of CO_2 and water vapour and derived from certain constituents of the electrode coating—and there is strong evidence that the composition of this gaseous envelope affects the constitution of the deposited metal. In my experience, which I must admit is rather limited, hydrogen is more important than carbon in this respect; there is in fact an excellent example given in the paper (though the authors do not draw attention to it) of the effect of hydrogen in determining the composition of the inclusions. I should like to refer to this later.

The only paper which has been published in this country giving the results of a sytematic experimental study of the constitution of weld metal, with particular reference to the inclusions and the gas content, is that by my colleagues, Mr. Rooney and Mr. Schofield, and myself, published by this Institute some two years ago.* For that work we used a series of modern methods, such as vacuum fusion, vacuum heating, alcoholic iodine, and X-ray diffraction analysis. By these means we were able to obtain a clear and accurate picture of the constitution of a series of mild-steel weld metals and to show how this constitution depends either on the composition of the electrode core wire or on that of the electrode coating; all the experimental results quoted by the authors are taken from work conducted at the National Physical Laboratory.

It seems to me that what the present authors ask us to do is to say that such experimental work is unnecessary and that we can, by the use of certain thermodynamical calculations, obtain a picture of the inclusions in weld metal with sufficient accuracy to be quite valuable. Here I cannot agree at all. In my view the discrepancies between the calculated and the experimental results are so great that it is not possible to place any reliance on the calculated results unless one has the experimental results with which to compare them.

I realize that that is a very sweeping criticism, and I should like to justify it in a few respects. To illustrate the proposed method the authors have discussed in detail two electrodes from the National Physical Laboratory work, electrodes *B* and *C*. With regard to electrode *C*, which is discussed in Table IV, they point out that there should be two separate stages of inclusion separation, one above the melting point and one on solidification. They say that in both stages the inclusions should have the same composition and should consist of rhodonite, although how from the calculated results in that table it is possible to deduce that the composition should be rhodonite I fail to see.

Figure F is a typical field of weld metal produced with electrode *C*. It will be seen that there is a series of large inclusions and also a sort of cloud of relatively small ones. It may be assumed that the large ones correspond to what the authors have called the inclusions which are formed above the melting point—the primary ones—and that the small ones are those which form on solidification. By chemical analysis and X-ray analysis we proved that all the inclusions are rhodonite. With regard to the sulphides in this weld metal, the authors say that calculations show this should be manganese sulphide, and in the National Physical Laboratory work we definitely identified manganese sulphide, so that this first weld looks rather hopeful.

Figure G shows weld metal from electrode *B*, and the inclusions are of an entirely different type; instead of the homogeneous glassy ones we have a characteristic duplex structure. I am afraid that this illustration was not prepared for this discussion and does not show a field in which there are many of the small inclusions present, but we find here again a cloud of small inclusions, which I presume can be considered to be the secondary stage of separation on solidification. Some of these can be resolved under a high-power microscope and seen to be also duplex. Here again we have two stages of inclusion separation, and according to experiment these two stages both produce the same type of inclusions, namely a mixture of iron silicate (fayalite) and iron oxide (FeO). This latter is not a pure oxide but a solid solution of manganous oxide (MnO) in FeO.

What do the authors say about this weld? They state (page 163 and Table II) that the inclusions formed above the melting point should be pure fayalite, whereas those formed on solidification should be (to use their own words) "iron oxide in fine dispersion." That is not what is found at all; the two inclusions are mixed up together in the form of the duplex ones shown in Fig. G.

With regard to the sulphides in this weld, it is a little unfortunate that the authors use the word "absent" in Table II in connection with the X-ray analysis for sulphides; it would have been preferable had they used the words which we use in our paper, namely, "not detected." There is quite a difference between a constituent not detected by X-ray analysis and one which is known to be absent. In weld metal *B* we obtained definite chemical evidence that sulphides do form part

Fig. G—Inclusions in weld (electrode *B*). Unetched × 1500

* H. A. Sloman, T. E. Rooney, and T. H. Schofield, *Journal of The Iron and Steel Institute*, 1945, No. II, pp. 127P–155P.

of the inclusions just as they do in electrode *C*, but for some reason these sulphides did not manifest themselves on the X-ray photograph. It may be that they have been too finely divided, and that the weak pattern from them was masked by the numerous and prominent lines of the fayalite and iron oxide structures. According to the authors' calculations sulphide has no tendency to form. Here again there is a very large discrepancy, which I do not see how we can get over. If theory says that sulphide should not be formed, then that particular aspect of the theory must be wrong.

Table V is the main table in the whole paper, and I should like to consider what results can be obtained by the method which is suggested by the authors. They start in this table by using the National Physical Laboratory total oxygen, manganese, and sulphur, and calculate the MnO, FeO, and SiO_2 from those figures. The results are given in the second horizontal division. My first point is that if we calculate the total oxygen from the figures given in this horizontal division, the values are all very much lower than the total oxygen from which the authors started ; they are between 20% and 50% low. The worst case is for electrode *E*, where the total oxygen as calculated from the authors' figures is 0·08% whereas the experimental figure is 0·14%.

The experimentally determined amounts of MnO, FeO, and SiO_2 are given in the fourth horizontal division, and the differences between these and the calculated values are shown in the fifth horizontal division. In every case the discrepancies are very serious, and it must be borne in mind that, unless the experimental values are available, it is impossible to ascertain the extent of the discrepancy in any particular case, since the only results which can be obtained by the present methods are those given in the second horizontal division. When, therefore, one is examining weld metal for which no experimental data have been obtained it is impossible to assess the value of the results derived solely by calculation.

From the amounts of the three oxides given in the second horizontal division the authors calculate the percentage compositions of the inclusions as shown in the third horizontal division. Since these compositions are derived from incorrect amounts of the three oxides it follows that they must themselves be wrong. The seriousness of the discrepancies is shown by a comparison of these calculated percentages with the experimentally determined ones given in the sixth horizontal division, and I should like to ask whether anyone who was given the percentage compositions in the third horizontal division of Table V could possibly deduce that the actual inclusions had the compositions given at the foot of the table.

Turning now to the effect of hydrogen on the composition of the inclusions, I should like to refer to electrodes *A* and *B* in Table V. Electrode *B* has a straightforward iron-oxide/silica type of coating which produces weld metal having the duplex iron-oxide/iron-silicate type of inclusion. Electrode *A* has a coating very similar in composition, except that a hydrogen-bearing compound—cellulose—is incorporated in an amount which increases the " potential hydrogen " of the coating to three times that of electrode *B*. The effect on the constitution of the deposited metal is quite remarkable ; the inclusions change over completely to rhodonite, and the extent of the change of composition is seen from the values given for the two weld metals in the sixth horizontal division. The point I wish to make is that these remarkable differences hardly show up at all in the corresponding calculated compositions, and I suggest that this is because the authors have not considered hydrogen in their equations.

The authors suggest that in order to determine the total oxygen, instead of using one of the standard methods employed by the Gaseous and Non-Metallics Sub-Committee we should calculate it indirectly from the FeO content of the slag. This seems a rather revolutionary idea to put forward at this time, in the light of the work of the Sub-Committee, and it is very unfortunate that the authors give us no figures to show that this assumption is justifiable. I wonder whether they have any. If they have it would be useful for us to know them, because if the total oxygen as calculated in that way is different from the experimentally determined total oxygen it seems to me that the discrepancies which I have discussed in Table V are going to be even worse than they are when the authors start off with the total true oxygen.

I would like to summarize by saying that to me this paper is extremely interesting from an academic point of view, but I cannot see that the method suggested is likely to have any practical use, except perhaps to indicate the mechanism by which inclusions may be formed.

Dr. **C. H. Desch,** F.R.S. (London) : Without offering any criticism on these papers, I should like to refer to the great improvements in technique which are being shown to us now. This X-ray examination on a micro scale actually dates from fifty years ago. As is mentioned by Betteridge and Sharpe, Heycock and Neville had a paper on it exactly fifty years ago, using X-ray transmission pictures, but they were dealing with a simple case, an alloy, for example, of sodium and gold, where the relative transparencies of the two constituents to X-rays were so different that fairly good photographs could be obtained. It is curious that since that time very few people have attempted to carry the process further. In recent years, in visiting France, I found a good deal being done in certain of the Paris laboratories, but this paper represents a great improvement in technique, giving X-ray transmission pictures which are almost comparable in definition with low-power photomicrographs, and in that way we shall be able to get a good deal more information about the character of these segregated materials.

I should also like to mention the work of Dr. Whiteley. From time to time Dr. Whiteley comes to see me and says " I have a rather interesting specimen here," and he produces one which is usually 1 c.c. in size, and under the microscope he is able to show me all kinds of things overlooked by previous students of metallography. I do not know anyone who can extract as much information from a very small specimen as Dr. Whiteley, and it does seem that it is still possible to improve the metallographic examination of very carefully polished specimens so as to get more information than has usually been obtained.

I would suggest also that there is room for more attention to be given to microchemical methods of analysis. Using spot reagents on a specimen under the microscope, and the well-known technique of chemical microscopy, it is possible to identify even quite small inclusions by the formation of characteristic crystals with certain reagents. It is a very pretty technique. It has been largely developed in America, at Cornell University. There is room for a good deal more work in that direction ; it is the kind of work that appeals to anyone who is neat-handed in dealing with quantities of the order of fractions of a milligram.

These papers are very valuable. I shall not attempt to discuss the thermodynamical aspects, but on the experimental side the techniques can be developed to such an extent that any theoretical speculations and suggestions, such as are given in the paper by Rollason

and Bishop, can be checked by direct experiment.

Dr. **L. Mullins** (Kodak, Ltd., Harrow) : Dr. Betteridge and Mr. Sharpe deserve hearty congratulations on the high standard of their paper, which so ably demonstrates the rapidly increasing scope of physical techniques in metallurgy. The illustrations reveal clearly that the technique is complementary with photomicrography, but it is perhaps as well to emphasize this point so that the method may be viewed in its proper perspective. Whereas the photomicrograph reveals the surface structure, the micro-radiograph provides a shadow picture of a thin slice of the material and is a two-dimensional image of a three-dimensional structure. It is for this reason that the specimen thickness must be comparable in thickness to the size of the particles in the specimen. An important difference is the relative tone rendering of the various components. It will be obvious from Figs. 10 and 11 in the orginal paper that the relative tones in the micro-radiograph depend on the radiation used. A further point which deserves emphasis is that the X-ray technique is restricted to the revelation of components which differ in X-ray absorption.

The detailed descriptions of the equipment and technique will provide valuable guidance to those utilizing micro-radiography for the first time. Two points, however justify some amplification. Firstly, as the special photographic plates are only thinly coated with an extremely fine-grain emulsion, the image does not attain the heavy blacks to which one is accustomed in ordinary photography, so that the image may, at a first glance, appear valueless. The authors have provided a valuable hint in indicating that development should not be extended beyond the stage where the image has a green tinge. Secondly, it may be mentioned that the developed graininess of the special plates used is very sensitive to the development conditions and may increase by increase of developed grain-size if development is extended. If this proves troublesome it may be preferable to develop the plate in D.158 developer, diluted with an equal volume of water.

There is one point in the paper which is not clear : on page 187 the authors mention the possibility of X-ray halation arising when radiographing near the edge of the specimen, unless the specimen is mounted on a piece of film base. Is this a reference to X-ray scatter ? If so, is the film base merely serving to reduce the intensity of the radiation around the edge of the specimen ? What increase in exposure is necessary under these circumstances ?

The work of the authors and others has demonstrated effectively the potentialities of micro-radiography, and one is prompted to suggest that investigations should be made on the metallurgical aspects of two other related techniques. In the first, use is made of the differences of electron emission from the elements in the specimen under X-ray excitation.* The technique is illustrated by Fig. H, in which it is seen that highly filtered X-ray radiation generated at about 200 kV. passes first through the photographic emulsion and then strikes the specimen, which is held in close contact with the former. Development yields an image corresponding to the distribution of the elements in the various parts of the specimen in contact with the film. The second technique of some promise, which may in fact be applicable to the present problem, is to use radio-active tracer elements for alloying. In due course, sections through the specimens are left in close contact with a photographic emulsion for some time when an image representing the distribution of the tracer elements is formed owing to their radio-active emission.

* *See*, for instance, J. J. Trillat, *Comptes Rendus*, 1942, vol. 214, pp. 164–166, and A. Guinier and J. Devaux, *Comptes Rendus*, 1942, vol. 214, pp. 223–225.

CORRESPONDENCE

Mr. **T. E. Rooney** (National Physical Laboratory, Teddington), referring to the paper by Rollason and Bishop, wrote that in the verbal discussion Mr. Sloman had dealt in some detail with certain aspects of the authors' application of published thermodynamical data for the determination of the compositions of inclusions in weld metal. The writer is in agreement with Mr. Sloman's criticism but desires to amplify such criticism from a somewhat different viewpoint.

In the authors' discussion on page 163 on the phase diagram for the system FeO–Mn–SiO_2 the impression is given that FeO and MnO can exist as separate phases. Experimental work by the alcoholic iodine method on steel and weld metal indicates that FeO and MnO when present together form solid solutions. This is in agreement with the work of Jay and Andrews* on the FeO–MnO system, which shows that solid solutions are formed throughout.

The authors refer to good agreement between their calculations and the results of experimental work at the National Physical Laboratory, but in many instances the agreement is anything but good.

Dealing with the types of inclusions which are likely to occur, the authors' interpretations have obviously been influenced by the results obtained by the alcoholic iodine method, but without such guidance it may be difficult to forecast a mixture of rhodonite and tephroite in the same sample, a result which has been obtained experimentally. Similarly, a picture of the following types may present some difficulty : (MnFe)O, (MnFe)O . Al_2O_3, 3(MnFe)O . Al_2O_3 . $3SiO_2$, 2(MnFe)O . SiO_2. The authors state on page 116 that the metal *AW*2 contains the normal rhodonite type of inclusion. This material in fact contains a modified rhodonite probably of the type MnO . $(SiTi)O_2$. Thus it might be inferred that fact is stranger than fiction in this respect.

The method of analysing the slag for FeO and deducing the oxygen content of steel thereby is ancient history in steelmaking, but it has been found necessary to study the inclusions from other angles ; hence the Inclusions Sub-Committee and the Gaseous and Non-Metallics Sub-Committee.

Finally, the authors' conclusion that the necessity for complicated and laborious inclusions analyses can be

* A. H. Jay and K. W. Andrews, *Nature*, 1944, vol. 154, p. 116.

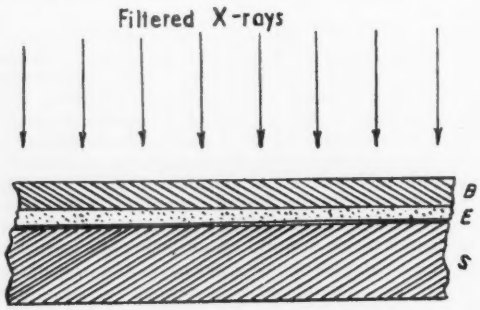


Fig. H—Diagram illustrating set-up for making electron radiographs, the photographic plate or film base *B*, and its emulsion coating *E*. Electrons liberated by the specimen *S* are recorded by the photographic emulsion

obviated by complicated, laborious, and inaccurate calculations is not impressive.

Weld metal provides a simple and profitable material for investigation by the alcoholic iodine method.

For the qualitative identification of inclusions the separation and identification can be carried out with reasonable speed, and if the determination is confined to the principal constituents—SiO_2, FeO, and MnO—quantitative examination can also be carried out simply and speedily.

Dr. **K. Winterton** (British Welding Research Association), wrote: The paper by Rollason and Bishop will be welcomed as an important theoretical contribution to a subject the practical aspects of which are attracting increasing attention. The solution of the thermodynamical equations gives results roughly comparable with the results of iodine analysis, although the authors' suggested method of determining the type and amounts of inclusions on weld metals by calculation seems a little optimistic. For accurate calculation the authors require a complete slag analysis, followed by arduous and tricky calculations, without sufficient proof of the reliability of the results.

With regard to the chemical form in which sulphur will occur in mild-steel weld metal, the authors' few comments appear to have a misplaced emphasis. They reach the unassailable conclusion that in liquid iron the sulphur will be largely in solution as either FeS or MnS. However, in the first weld metal they consider (weld metal *B*), they state that since 25% of the iron of FeO–FeS can be replaced by manganese, MnS should not separate during solidification, and further that iron sulphide is known to be appreciably soluble in mild steel. The first argument is not valid, since no FeO–FeS is present at that stage.

For a second weld metal considered (weld metal *C*) it is stated as a theoretical deduction (Table IV) that MnS is formed on solidification, although the only basis for this statement appears to be that the manganese content is rather high.

Owing to the low solubility of both MnS and FeS in iron at low temperatures it seems likely that one or both compounds will be precipitated at some stage in almost all mild-steel weld metals. McCance* has examined the important partition of sulphur between iron and manganese by two methods, first by directly using the results of Meyer and Schulte, and second by calculation from the dissociation pressure values of Britzke and Kapustinsky.† In selecting the latter method as the more reliable, McCance found that at 1600–1500° C., and with about 0·25% of manganese, over 90% of the sulphur will be present as FeS. At lower temperatures the balance reverses, so that at 900° C. only 17% of the sulphur will be present as FeS. In practice this reversal of equilibrium is likely to be incomplete, so that a considerable proportion of iron sulphide may be expected to be precipitated. McCance shows that these views are in accordance with the findings of Whiteley,‡ to whose work the authors refer.

While this criticism will not detract from the importance and interest of the paper, which represents a bold and stimulating contribution to the subject, it emphasizes the need for much more practical and theoretical work.

* *The Iron and Steel Institute*, 1938, *Special Report No.* 22, pp. 331–371.

† Britzke and Kapustinsky, *Zeitschrift für anorganische Chemie*, 1933, vol. 213, p. 71.

‡ J. H. Whiteley, *The Iron and Steel Institute*, 1937, *Special Report No.* 16, p. 23.

AUTHORS' REPLIES

Dr. **J. H. Whiteley** replied: I wish to thank Mr. Burton and Dr. Desch for their encouraging remarks. Since the paper has not been criticized in any way, only one further comment is needed. By some mischance the captions under Figs. 1 and 2 (page 94) have been transposed. That under Fig. 1 belongs to Fig. 2 and *vice versa*.

Dr. **W. Betteridge** and Mr. **R. S. Sharpe** replied: We wish to thank contributors to the discussion for the interest shown and we are particularly pleased that both Dr. Jones and Mr. Wolfe are finding the technique of service. Mr. Burton's comment on the envelopes of dense material surrounding the manganese-rich regions shown in Figs. 3 and 4 is very pertinent, as the bonding forces between the segregate, or inclusion, and the matrix will be modified by the envelope and will have some influence on the effect of the segregate on the mechanical properties of the steel; such envelopes, if they consist of a material in which manganese is insoluble, could explain the failure of the manganese-rich regions to diffuse into the matrix. It is of interest to note that the massive sulphide inclusions in nickel–iron meteorites frequently have an envelope of phosphide and the study of these might lead to interesting conclusions applicable to the corresponding microscopic inclusions in steels.

We are gratified that Dr. Jones finds the technique satisfactory and agree that in its present state the scale of the structure which it is possible to resolve is controlled both by the photographic emulsion and by the minimum thickness of sample obtainable. Within our experience the latter appears to be between 0·0005 in. and 0·001 in., and attempts to carry the polishing further have led to the sample breaking up. Thus the scale of a structure which it is desired to resolve must not be much finer than this limiting size if a large proportion of the constituent searched for is present. If a small proportion is present, however, so that the possibility of the images overlapping is slight, the minimum size of the characteristics which can be detected is much less than the thickness of the sample, and is limited only by the grain-size of the emulsion; with high contrast there is no difficulty in detecting stringers and inclusions less than 0·0001 in. across.

Mr. Wolfe's application of micro-radiography to the study of machinability appears to be a promising field of work, but we are not convinced by the radiographs shown that the manganese-rich regions are disappearing after the longer periods of tempering. Judgement on the basis of reduced contrast is very suspect after three photographic processes, and the reduction in sharpness of the images is very slight. The absence of diffraction lines due to a second phase cannot be accepted as proof that the manganese-rich regions are not such a separate phase, since an estimate based on Mr. Wolfe's micro-radiographs suggests that they are only present to the extent of about 0·5% by volume—far below the usual level of detection. Nevertheless Mr. Wolfe's suggested mechanism of the effect of the segregates on the mechanical properties of a steel follows very closely that proposed in the conclusions of our paper and we hope that he will be able to develop it further.

We agree entirely with Dr. Mullins that micro-radiography and photomicrography are complementary and also with his recommendation as to the developer to give minimum grain-size. Since the paper was written we have changed to D.154 developer, which is very similar to D.158; the slight reduction in contrast is not found to be detrimental. The effect of film base in reducing X-ray halation is, we think, due to the absorption of the softest components of the direct X-ray beam

which otherwise would cause excessive blackening in the emulsion adjacent to the image of the specimen. These soft components would, in any case, be absorbed in the sample itself so that little increase in exposure is found to be necessary. Film base was chosen merely because it was a grainless material with a suitable absorption ready to hand. The other two techniques described by Dr. Mullins are interesting, but the former lacks the possibility of identifying unknown segregating elements since the short-wavelength radiation used to excite the electron emission is far removed from critical absorption edges. The use of radio-active tracer elements is likely to become quite common now that a wide range of artificial radio-active elements is becoming available.

Dr. Desch's kind remarks are much appreciated and we hope that the development of the experimental technique will continue and, with the necessary improvement in photographic emulsion, will lead to further increased resolution.

Dr. **E. C. Rollason** and Mr. **E. Bishop** wrote in reply : In answer to Mr. Burton, care must be taken to make large deposits, and to reject those portions which may contain admixtures from the parent plate.

Table V is of main importance, and in view of the arguments raised in the paper, it is surprising that Mr. Sloman should consider the discrepancies between the calculated and analysed oxide contents to be a refutation of the theory. The first horizontal division gives the amount of oxygen still in solution in the weld metal, and if this is added to the weight of oxygen in the inclusions, given in the second division of the table, the total will be found in all cases to be exactly equal to the total oxygen content of the weld metal as found by vacuum-fusion analysis. Table V establishes the fact that part of the inclusions form while the metal is still molten, and the remainder during and after solidification.

It would appear that too much emphasis has been made on p. 163 regarding the formation of iron oxide in fine dispersion due to the high calculated silicon content ; but it is mentioned in the paper that some doubt is thrown on the thermodynamic data for the Si–O equilibrium.

With regard to the sulphur there is much difference of opinion. It is assumed in the paper that the sulphur precipitates simultaneously with the residual soluble oxygen while the weld metal is cooling from its freezing point. If MnO and SiO_2 are forming under these conditions, MnS will also form. Since it is immiscible with manganese silicate, a separate MnS phase will be obtained. If, on the other hand, Fe(Mn)O is being formed, the sulphur will combine as Fe(Mn)S. These two compounds, as is pointed out in the paper, are miscible up to high manganese contents. Hence, an oxide–sulphide phase is formed.

The actual experimental data on sulphides in fayalite-type weld metal, given in the paper by Sloman and co-workers, are unsatisfactory. There is chemical evidence for the presence of sulphides, but no X-ray crystallographic evidence. Sloman and co-workers choose to assume that MnS is present but not detected, but this is merely a matter of opinion. It is equally valid to assume that the sulphide detected chemically was Fe(Mn)S in solid solution in Fe(Mn)O, and that crystalline MnS was not detected simply because it was not there.

It is unfortunate that Sloman and co-workers should take the view that the paper is intended entirely to eliminate the necessity for vacuum-fusion and iodine analysis. It is based almost completely on their experimental results, and needs to be verified or discarded on the basis of as many more results as possible. There are many cases, however, in which some indication of the probable inclusion content of a weld metal is needed, but in which a complete iodine-residue analysis is unjustified. It may well be that the authors' hypothesis of the mode of formation of inclusions is premature, and that their conclusions are optimistic, as has been suggested, but in this branch of study, as in all others, theory and experiment must proceed hand in hand.

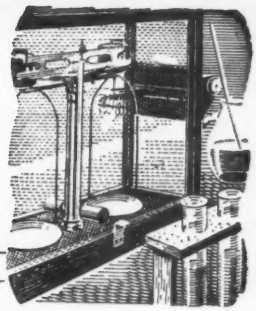
DISCUSSION ON PAPERS, SPRING MEETING, 1948

In addition to the foregoing discussion the August issue of the *Journal* contained the discussion on the following papers : " Construction and Repair of Open-Hearth Furnaces " by D. C. Muir ; " The Design of Open-Hearth Gas Ports " by M. P. Newby ; and " The Installation and Use of Instruments on Open-Hearth Melting Furnaces " by R. C. Baker (pp. 376–384).

The remaining discussion, on the papers " A Comparison of Moulds of Standard Composition and of Approximately Ingot Mould Sub-Committee Composition " by W. L. Kerlie ; " Mould Weight/Ingot Weight Ratio and Its Relation to Mould Consumption " by N. H. Bacon ; " Ingot Surface Defects " by P. Walker ; and " Abnormal Creep in Carbon Steels " and " The Creep Properties of Molybdenum, Chromium–Molybdenum, and Molybdenum–Vanadium Steels " by J. Glen, will be published in the October issue (pp. 139–150).

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



An Experimental Furnace for the Investigation of Open-Hearth-Furnace Combustion Problems

Part III—STUDIES WITH THE MAERZ PORT AND VARIOUS MODIFICATIONS THEREOF

By J. F. Allen, B.Sc., J. H. Cook, B.Sc., and G. Fenton, B.Sc.

SYNOPSIS

The experimental furnace described in Part I of the present series of papers was modified to a Maerz design and experiments were conducted under various operating conditions with this and other modified ports. The effects of gas rate, air/gas ratio, and operating pressure were substantially the same as reported for earlier designs, but in general the performance obtained with the Maerz port, and particularly with certain modifications of it, was superior to that obtained with ordinary ports. A new design was found to give exceptionally good results and the application of this to practice is discussed.

I—INTRODUCTION

THE experimental furnace used in the investigation to be discussed was that described in Part I of the present series of papers,[1] modified to a Maerz furnace. The experimental procedure was again the determination of " characteristic curves " (referred to as *C*-curves) showing the relationship between the heat entering the furnace and the heat transferred to the hearth, *i.e.*, useful heat. In the series of experiments to be described, curves have been prepared for the Maerz port and for various modifications of it; as in the experiments with the conventional port design (*see* Part II[2]), the effects of air/gas ratio and furnace pressure have been studied for the various modifications of the port.

The *C*-curves determined experimentally cover a range considerably wider than that under which production furnaces operate, *i.e.*, from a gas rate corresponding to that which in production conditions would be insufficient to melt steel to that which would cause severe damage to the refractories. From consideration of scales of heat input per unit of hearth area and of " Thring number,"* the equivalent steel-making range in the *C*-curves is from 11·0 to 17 therms per hour heat input.

II—DESIGN OF THE EXPERIMENTAL FURNACE

The furnace used in the present investigations is illustrated in Fig. 1. The Maerz block employed as a basis for modifications was modelled on that used in the *K* furnace at the Templeborough melting shop of Messrs. Steel, Peech and Tozer.†

The layout of the ancillary plant remained as described in Parts I and II, the same care being taken to ensure correct similarity. All the experiments were carried out with a mixture of blast-furnace gas and coke-oven gas, in such proportions as to give the mixed fuel a calorific value of approximately 180 B.Th.U. per standard cubic foot.

The various modifications of the Maerz port which were used in the experiments are shown in Fig. 2, all these modifications falling within the general framework of the model illustrated in Fig. 1. These port designs are subsequently referred to as port designs Nos. 3 to 8, port designs Nos. 1 and 2 being those used in the experiments described in Part II. With each port design some variation of gas-port and " air

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* *See* M. W. Thring, *Nature*, 1947, vol. 159, Feb. 8, p. 203.

† A diagram of this furnace is given in *The Iron and Steel Institute*, 1946, *Special Report No.* 37, p. 7.

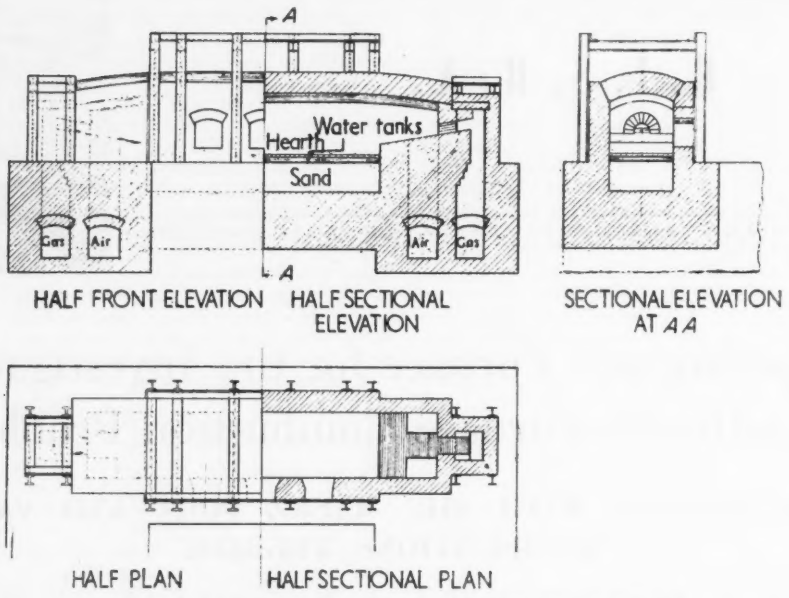

Fig. 1—Arrangement of experimental open-hearth furnace

port " (*i.e.*, the uptake in the case of the Maerz port) area was made, and these are tabulated in Table I.

Port design No. 4 is based on a design submitted by members of the British Iron and Steel Research Association's staff to the Association's Steel Practice Committee early in 1946. Port design No. 7 is based on a design originally proposed by Mr. S. W. Pearson of Messrs. Steel, Peech and Tozer in 1943, but which was not built at the time because of war-time inability to make substantial changes in design. Port design No. 8 is a development suggested by Dr. A. H. Leckie of the British Iron and Steel Research Association in the course of the present experiments.

III—EFFECT OF OPERATING FACTORS

Although the object of the present work was

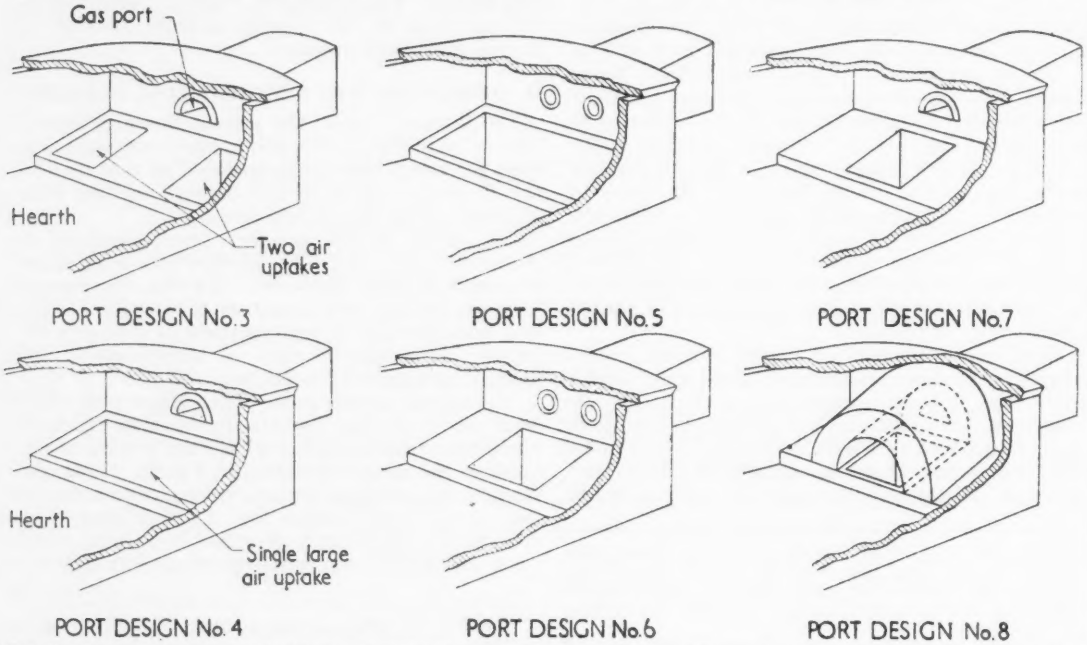

Fig. 2—Experimental port designs. Port design No. 3 is the ordinary Maerz design, and port designs Nos. 4–8 are special designs

primarily a study of port design with special reference to the Maerz port, an investigation of the effect of operating factors such as gas rate, air/gas ratio, and furnace pressure was made with each port design. This was essential in order to ascertain whether the effects of these operating variables (already investigated in detail for a conventional furnace and reported in Part II) were the same for each form of Maerz port.

(*a*) Gas Rate

Variable gas rates were studied in order to obtain *C*-curves. As would be expected, high gas flows gave, in general, higher values of heat transfer to the hearth. A series of such curves for the Maerz furnace and its modifications, using various air/gas ratios and port designs, is shown in Fig. 3. The exceptionally high heat transfers with port design No. 8 are of great interest and are the subject of discussion later in this paper.*

The theory of *C*-curves has been discussed in earlier papers[1, 2, 3] and it may suffice here to state that the occurrence of a maximum within the limits investigated is strongly indicative of poor port design giving incomplete combustion at high rates of gas flow. Such curves were obtained with certain conventional furnace designs (*see* Part II, Figs. 1 and 2) and with the ordinary Maerz block. Although the heat transfer to the hearth is greater in the latter case, this may, at least in part, be attributed to the greater block-to-block distance (a feature of the Maerz furnace) and the consequent longer time the gases are in the furnace. It can be seen from Fig. 3, however, that in the later modifications of the Maerz port this

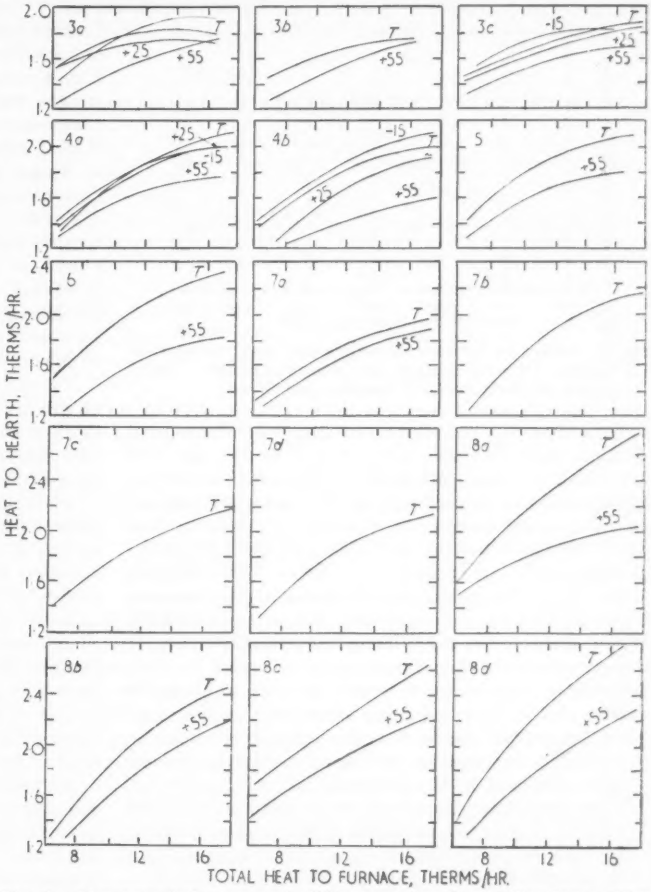

Fig. 3—Characteristic curves for Maerz port and modifications. The figures in the top left corners of the graphs refer to port design numbers as tabulated in Table I; the figures against the curves denote percentage excess or deficiency of air (*T* = theoretical). The furnace pressure in all the experiments was + 0·02 in. W.G.

maximum is eliminated; this is a result of the more intimate mixing due to the direct impingement of the gas and air streams. It seems, therefore, that combustion conditions in the normal Maerz furnace are not entirely satisfactory, and modifications which allow the periphery of the gas stream to be surrounded completely by the air stream result in greatly improved combustion conditions.

(*b*) Air/Gas Ratio

The effects of excess air have been discussed in Part II, where it was observed that the best thermal

Table I
AREAS OF PORTS USED

Port Design No.	Gas Ports		Air Uptakes	
	Number	Total Area, sq. in.	Number	Total Area, sq. in.
3*a*	1	26	2	221
3*b*	1	19	2	221
3*c*	1	9	2	221
4*a*	1	26	1	319
4*b*	1	9	1	319
5	2	23·5	1	319
6	2	23·5	1	86
7*a*	1	26	1	86
7*b*	1	9	1	86
7*c*	1	26	1	51
7*d*	1	9	1	51
8*a*	1	26	1	86
8*b*	1	9	1	86
8*c*	1	26	1	51
8*d*	1	9	1	51

*It will be observed, however, that with port design No. 8 the heat transfer to the hearth is lower than with the other designs at low gas flows. It is tentatively suggested that with this design combustion takes place in the block at low gas flows, with consequent reduction in heat transferred to the hearth, since that proportion of the flame developed in the block is unable to radiate to the roof or the bath. As the flow and the proportion of flame outside the block increase, the beneficial effect of rapid combustion becomes apparent. The lower heat transfer at low gas flows is, however, more of academic interest, since the equivalent steelmaking range of heat input (or flows) is from about 11·0 therms per hour upwards.

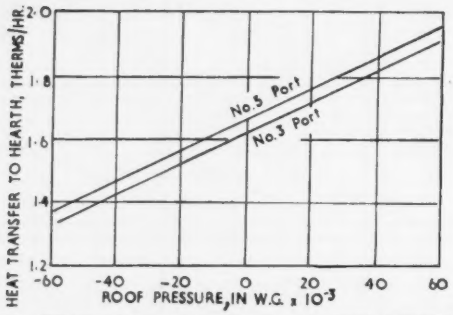

Fig. 4—Effect of furnace pressure on heat transfer to hearth (Maerz design and modifications). Heat input to furnace 10·7 therms per hour

performance was generally obtained with theoretical air and that the necessity to use excess air was indicative of poor port design. Recently, however, Robertson[4] has pointed out, from a series of chemical analyses made during the working of charges, that whilst this may be true for the experimental furnace, in which only combustion takes place, the oxidation of the charge in the production furnace may demand a quantity of oxygen equivalent to as much as 15% of the combustion air. Thus some modification of the original recommendations may be called for, but the statement that the necessity of using appreciable excess air to burn the gas efficiently implies bad port design still stands, for the following reasons :

(i) The experiments described in Part II showed that (contrary to the observations with excess air) appreciable deficiency of combustion air did not lead to serious deterioration of performance. Thus the failure to supply excess air to compensate for chemical oxidation may not be serious.

(ii) The observations of Robertson (and of other investigators studying chemical oxidation) were made on furnaces in which considerable excess combustion air was supplied and in which the infiltration inevitably associated with production-furnace working took place. Oxidation of the charge may therefore have been unduly large, and in a sealed furnace oxidation might be considerably less than that corresponding to 15% excess air.

The curves in Fig. 3 show the effect of air/gas ratio with the various forms of Maerz port. It soon became clear that the trend of effect was similar to that previously observed, and the full range of air/gas ratios was not investigated for every port modification. It is shown later (Part IV), however, that there exists one factor which encourages the use of excess air in production furnaces. This is that it is sometimes possible to obtain slightly increased heat transfers to the hearth *for a given limited maximum roof temperature* by using excess air. This advantage is obtained, however, at the expense of greatly increased fuel consumption, so that the economics of this procedure demand careful scrutiny.

(c) Pressure in the Working Chamber

In Part II the value of working a furnace at as high a pressure as is practical was decisively shown. In the present study a series of curves with the furnace pressure as the sole independent variable was obtained on the Maerz furnace and its modifications ; Fig. 4 is representative of these curves and demonstrates that as the pressure is increased there is a progressive increase in heat transferred to the hearth. Whilst this is in general agreement with the results of similar experiments carried out with orthodox port designs (*see* Part II, Fig. 5) there is one rather notable difference. With the orthodox furnace little additional benefit was derived from an increase in roof pressure above + 0·03 in. W.G. (corresponding to about 0·08–0·1 in. W.G. in a production furnace). With the Maerz designs (Fig. 4) the heat transfer continued to rise up to the highest experimental pressures (0·06 in. W.G.).

The theory governing the optimum roof pressure at which to run a furnace[5] has already been discussed in Part II and may be summarized by the statement that it is thermally economic to stop all air infiltration by increasing the pressure in the working chamber to such an extent that the atmospheric-pressure line falls to sill level, even at the expense of considerable escape of flame. This pressure increase is limited in practice by the damage caused by excessive flame escape. In the model furnace atmospheric pressure at sill level corresponds to a roof pressure of + 0·03 in. W.G., or to 0·08–0·1 in. W.G. for full-sized furnaces. Simple theory indicates no advantage in higher pressures owing to increasing escape of flame, and whilst this was confirmed in the earlier work, the Maerz designs would appear to benefit from still higher pressures.

At present the authors have to record this experimentally observed fact without being able to offer an explanation which covers all the aspects satisfactorily. However, a number of factors suggest themselves, any one of which may offer a partial

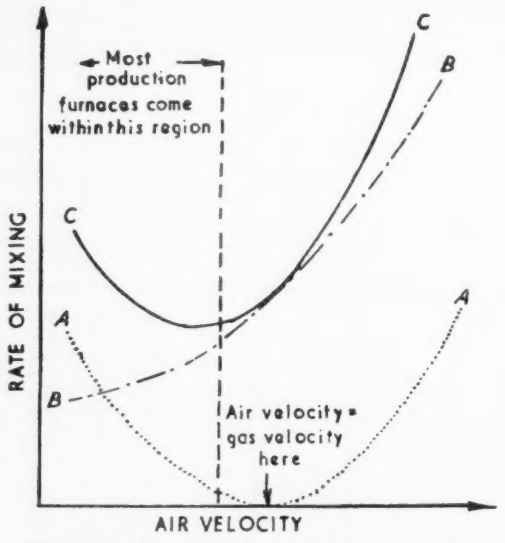

Fig. 5—Effect of air velocity on mixing for a given gas velocity. Curve *A*, mixing due to difference of velocity; curve *B*, mixing due to absolute velocity; curve *C*, net mixing rate attained

explanation of such behaviour. For instance, the theoretical optimum pressure is calculated on considerations of static pressure alone, without reference to the possible effect of the dynamic conditions in the furnace upon infiltration. Since flame velocity and shape may vary considerably among different port designs, it is quite reasonable to expect discrepancies between the observed effect of pressure changes and that calculated from theory. Also, theory presumes a furnace structure free from substantial leakages. Since both in the later experiments with the Shelton model (when some of the structure was over two years old) and in normal practice the working chamber is far from gas-tight, the apparent advantage of a roof pressure somewhat higher than the theoretical optimum is not unreasonable.

The observed departure from theory, whether or not partially explained by the above considerations, has no effect on the conclusions previously reached, and also confirmed on Maerz furnaces, namely, that high working-chamber pressures are desirable in practice. However, until the outer structure of furnaces is substantially modified (*e.g.*, by better-fitting doors, extended application of judicious water cooling, and modified door-lifting gear) it is often not practicable to work at the theoretical optimum pressure, quite apart from any high pressures demanded by dynamic considerations. Another practical point is that in some furnaces which tend to be over-checkered, diminution of waste-gas volume brought about by eliminating air infiltration causes a fall in checker temperature. Nevertheless it may still be recommended that production furnaces be worked at the highest roof pressure that conditions will permit.

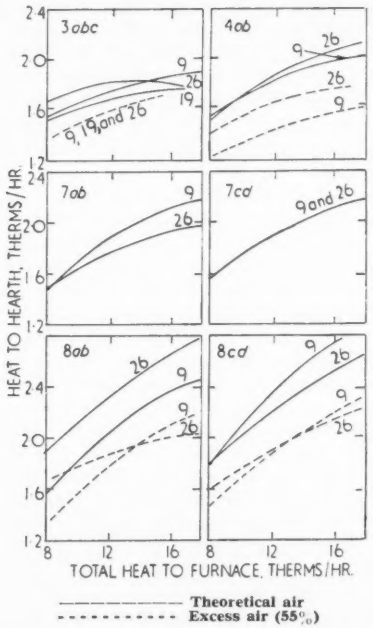

Fig. 6—Effect of gas-port size. The figures in the top left corners refer to port design numbers as tabulated in Table I; the figures against the curves denote gas-port area (square inches)

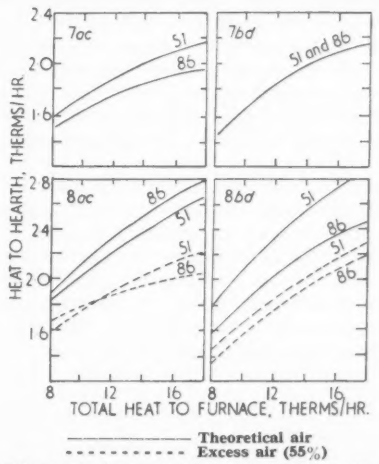

Fig. 7—Effect of air-port size. The figures in the top left corners refer to port design numbers as tabulated in Table I; the figures against the curves denote air-port area (square inches)

IV—PORT DESIGN

(*a*) General

Under the above heading it is intended to discuss both the size (cross-sectional area) of the gas and air ports, and the shape, configuration, or arrangement of these ports. In Part II the following main conclusions, based on experimental observation with the model of an orthodox port design, were reached :

(1) To ensure rapid mixing of gas and air the furnace should have either a small gas port and a very large air port, or a large gas port and a small air port. Intermediate areas are not desirable.

(2) The large port should surround the small port as far as possible.

(3) The small port (either gas or air) should be divided into two or more sections rather than have only one opening.

These conclusions agree with those (based on laboratory work) of Rummel,[6] who states that factors favouring rapid and efficient mixing are :

(1) A large difference between the velocities of gas and air.

(2) High velocities of both the gas and the air streams.

(3) Excess air.

It was shown that excess air increases the waste-gas losses and that any beneficial effects excess air gives in assisting rapid mixing are therefore obscured.

A tentative theory to account for the experimental observations (particularly that suggesting that an intermediate value of port area is undesirable) was included and illustrated in Part II and is considered of sufficient importance to repeat the illustration here (Fig. 5). The hypothetical rate of mixing, given a constant gas-port size (*i.e.*, gas velocity), is plotted for a range of air-port sizes (*i.e.*, air velocity). Curve *A* represents the mixing due to difference of air and gas velocity, and curve *B* that due to air velocity *per se*. The total mixing effect is given by the sum of these curves (*i.e.*, curve *C*) which shows a minimum mixing effect in a region of intermediate port sizes.

This argument takes into consideration velocity effects alone but the relative angle of the air and gas directions is comparatively small in orthodox port designs and is probably not sufficient to modify substantially the velocity arguments previously used. The existence of this angle will obviously assist overall mixing, but will not affect the general argument of Fig. 5.

In the Maerz furnace, and particularly in certain of the modifications used, the air and gas enter the working chamber at approximately right-angles to each other, and this introduces an entirely new factor, namely, that of angle of impingement. Before discussion of this the experimental results obtained with varying port sizes and designs within the general Maerz framework will be dealt with.

(*b*) Port Sizes

In Figs. 6 and 7 some of the curves of Fig. 3 are re-plotted to show the effect of gas- and air-port sizes. The results are conflicting in the case of the ordinary Maerz port (port design No. 3), and in the modifications Nos. 4*a*, 4*b*, 7*c*, and 7*d* the effect of port size was not significant, whilst the curves for port No. 8 (and also for port No. 7*a*) show a sufficient

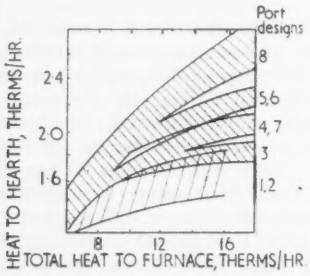

Fig. 8—Zones of heat transfer attained with various port designs

separation to suggest a real effect of port size. This difference is not, however, consistent, as sometimes the large gas or air port and sometimes the small shows the higher heat transfer. From this it must be concluded that in the Maerz furnace there is no apparent correlation between gas- and air-port sizes (*i.e.*, gas and air velocities) and heat transfer to the hearth. This may be because :

(1) In orthodox furnaces (and in Rummel's model work) the angle of incidence between the two mixing streams is fairly small whereas in the Maerz furnace the angle was of the order of 90°. The effect of this large angle in promoting efficient mixing will tend to swamp the effect of port size.

(2) A large variation in the Maerz air-port sizes causes only a small variation in the component velocity of the air parallel to the gas stream.

(*c*) Port Configuration

The effect of port configuration is shown in Fig. 8. This is not illustrated as a series of characteristic curves but as a number of bands (referred to subsequently as characteristic bands, or *C*-bands), as this method shows up the effect of port configuration more clearly. These bands are of such a width as to embrace all the *C*-curves for a particular air/gas ratio and furnace pressure, *i.e.*, they include all gas- and air-port sizes. Thus for any given set of operating conditions they show the effect of configuration alone. From Fig. 8 it will be seen that :

(*a*) The ordinary Maerz block gives somewhat better results than the conventional block (bands 3 and 1).

(*b*) Modifications of the Maerz block designed to bring the air stream directly underneath the gas issuing from the gas port show better results than the ordinary Maerz block (bands 4, 7, and 3).

(*c*) The use of twin gas ports gives better results than a single port (bands 5 and 6).

(*d*) The best results of all were obtained with port design No. 8. This is discussed separately, as a port of this design may involve some difficulty in practical application.

These results support the view that one of the most important features influencing mixing is the angle of impingement of gas and air, which is very favourable in the Maerz modifications. It will also be observed that the suggestions made in Part II that twin ports are preferable to single ports in promoting good mixing has been amply confirmed.

V—ANALYSIS OF HEAT DISTRIBUTION IN THE HEARTH

(*a*) Effect of Port Design

In addition to the study of the effect of variables on the total amount of heat transferred to the hearth it was possible, by means of the technique outlined in Parts I and II, to analyse the proportions of heat received by various sections of the hearth. That is, the hearth consists of four main water calorimeters and each calorimeter is fitted with resistance thermometers in order to determine the temperature rise in each calorimeter. The volume of water passing through the hearth is metered and hence the amount of heat transferred to any particular quarter of the hearth is easily calculated. These values can then be expressed as a percentage of the total heat transferred to the hearth.

The nomenclature used for describing the divisions of the hearth is the same as that adopted previously (Parts I and II), *i.e.*, No. 1 tank refers to the quarter of the hearth nearest the outgoing gas and No. 4 tank refers to the quarter nearest the incoming gas end of the furnace.

Some of the results obtained from analysing the heat distribution in this way are shown in Fig. 9. The full lines refer to the percentage of the total heat transferred to the hearth which enters each tank, whilst the dotted line represents the "range," *i.e.*, the greatest difference in the amounts of heat received by each tank. A zero value for the range would mean exactly equal distribution of heat among all four tanks. A good indication of the rapidity of combustion or rate of mixing is given by the proportion of heat transferred to No. 4 tank, and also by the shape of the range of the curves.

By comparison with Fig. 19 of Part II it will be seen that a greater proportion of heat reached No. 4 tank in the Maerz designs than in the orthodox designs, with a correspondingly smaller range. This

is indicative of more rapid mixing in the Maerz design. It must be remembered, however, that the greater block-to-block distance inherent in the Maerz design might give the effect of earlier combustion relative to the hearth tanks as compared with the orthodox furnace. However, the general configuration of the curves as compared with those obtained from the orthodox model suggests that the more rapid mixing in the modified Maerz furnace is largely due to the port design itself and not to the greater block-to-block length.

With the normal Maerz design most heat is transferred to tanks 1 and 2 (Fig. 9, (*a*) to (*c*)). As the gas flow increases, the flame length becomes greater and complete combustion occurs still further from the gas port, as illustrated by the divergence of curves 1 and 2 from curves 3 and 4. The effect of excess air in assisting mixing is shown by the higher positions of curves 3 and 4 where excess air is used and also by the slight decrease in range and the proportion of heat reaching each tank.*

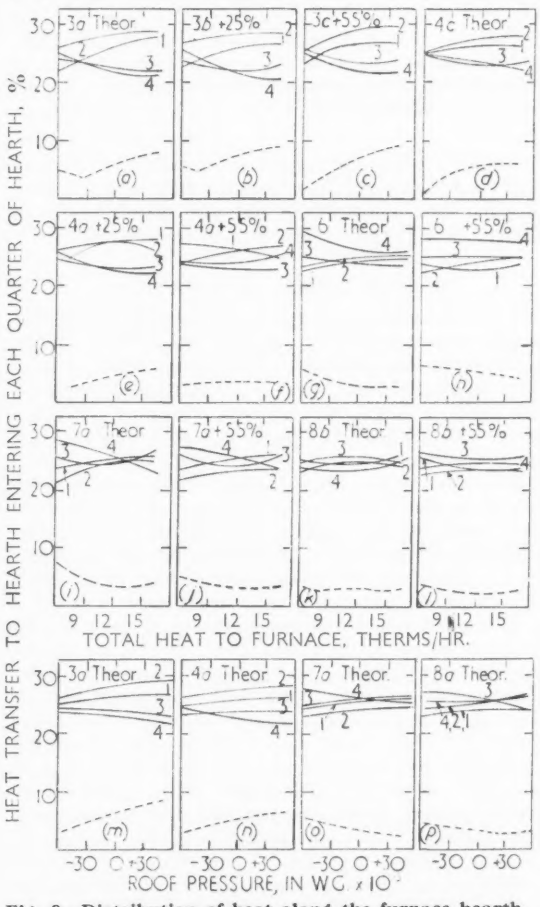

Fig. 9—Distribution of heat along the furnace hearth. The figures at the top of each rectangle refer to port design number and percentage of excess air. The figures against the curves refer to each quarter-hearth (*see* p. 42). The full curves represent heat distribution (%); the broken curves represent range (non-uniformity) of heat distribution (%)

When the air port is enlarged to the full width of the furnace (Fig. 9 (*d*) to (*f*)) the range is substantially decreased, although tanks 1 and 2 still receive most of the heat. Combustion in this case is more uniform along the furnace. There is a greater overall heat-transfer to the hearth in this design than the normal type Maerz furnace.

With the twin gas-port types (Fig. 9 (*g*) and (*h*)) combustion appeared to be advanced to such a degree that tank No. 4 obtained the greatest proportion of heat transfer to the hearth when excess air was used. There was some evidence of this also when using theoretical air; though the order of the curves in Fig. 9 is anomalous, the actual difference is small enough to be considered as uniform distribution at normal gas rates. Port No. 7 (Fig. 9 (*i*) and (*j*)) also gives rapid mixing, and at low gas flows No. 4 tank receives the most heat, although, as the gas flow and flame length increase, No. 4 tank receives proportionally less heat, thus increasing the degree of uniformity.

With port No. 8, mixing is rapid, but apparently not as rapid as in some of the other ports, as in no case does No. 4 tank receive most heat (Fig. 9, (*k*) and (*l*)). It is rather surprising at first to observe that although port design No. 8 gives higher total-heat transfers than any other type (Fig. 8), the zone of initial combustion is apparently not specially far advanced. This is probably due to the profound influence of radiation from the roof on the distribution of heat along the hearth and to the different roof configuration of port No. 8. The distribution of heat along the hearth is, however, remarkably uniform.

(*b*) Effect of Furnace Pressure

The effect of furnace-roof pressure on heat distribution along the hearth is shown in Fig. 9, (*m*) to (*p*). It is seen that with port designs giving less-rapid combustion (*e.g.*, port designs Nos. 3 and 4) the range (non-uniformity of heat distribution) tended to increase with pressure, whilst with ports giving very rapid combustion (*e.g.*, port designs Nos. 7 and 8) the effect of increasing the pressure was to decrease the range, *i.e.*, to make the heat distribution more uniform. This may be understood by a simple analysis of the factors governing heat distribution.

The heat distribution is made non-uniform because the flame tends to be hotter at the outgoing end (Nos. 1 and 2 tanks), since it requires time and length to develop. On the other hand, factors tending to make the heat distribution more uniform are (*a*) cold-air infiltration, which cools the hot outgoing end of the hearth more than the incoming end, which is already cool, and (*b*) the fact that much of the heat transfer to the hearth is by radiation from the roof, so that the interchange of radiation between the hot roof at the outgoing end and the cool hearth at the incoming end, or between the cool roof at the incoming end and the hot hearth at the outgoing end, tends to even up the heat distribution.

With ports giving slow flame development the inherent non-uniformity of heat distribution is very great, the effect of roof radiation is somewhat less

* Compare with Fig. 3, which shows that excess air eliminates the maximum in the *C*-curve.

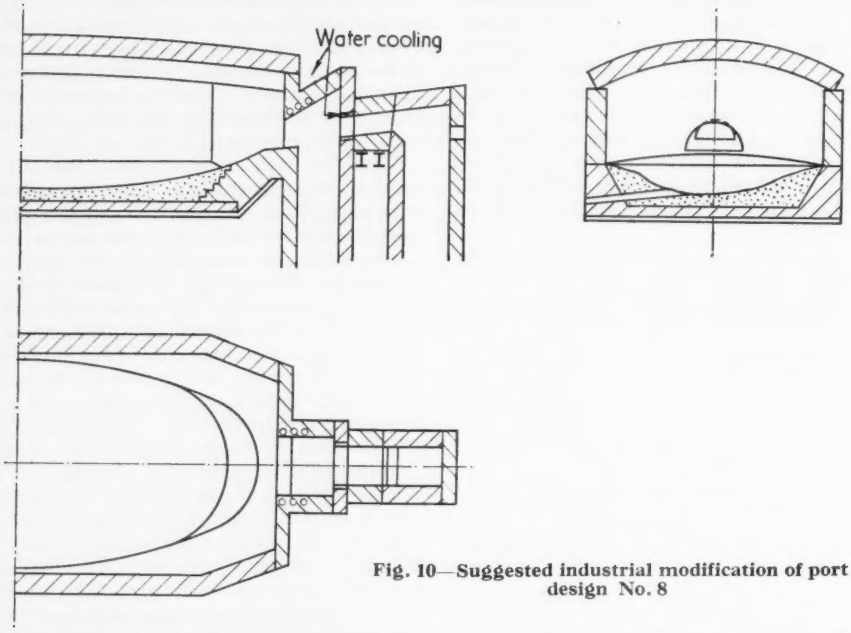

Fig. 10—Suggested industrial modification of port design No. 8

powerful, and the effect of increasing roof pressure so as to eliminate factor (*a*) (air infiltration) causes the range (non-uniformity) of heat distribution to rise. On the other hand, if the port gives rapid combustion there is less inherent non-uniformity and the roof is hotter, so that the effect of over-all roof temperature as an evening influence is enhanced and exceeds that of air infiltration. Therefore, as the effect of increasing the furnace-roof pressure is also to increase the general intensity of wall and roof radiation, under such circumstances the range of heat distribution may well decrease.

Incidentally, if a set of *C*-bands, as in Fig. 7, is drawn with roof pressures as the abscissæ instead of heat input to the furnace, the port configurations appear in the same order. This confirms that the main effect of increasing roof pressure is to eliminate infiltration and that any effect on combustion conditions is only of secondary importance.

(c) Effect of Air/Gas Ratio

The effect of excess air in speeding up combustion may also be seen in Fig. 9, where the curves relating to 55% excess air generally show a somewhat higher proportion of heat transferred to the hearth nearer the ingoing end, owing to the effect of the excess air in securing earlier combustion. Nevertheless the *C*-curves (Fig. 3) show that the benefit of the somewhat earlier combustion is entirely lost owing to the cooling effect of excess air.

(d) General

To sum up, it may be said that the higher heat transfers are associated with more uniform distribution of heat to the hearth and that to obtain these high heat transfers the development of complete combustion must be speeded up and brought nearer to the incoming gas port. Where combustion is occurring reasonably early increase of furnace pressure not only increases over-all heat transfer and furnace wall temperature, but also makes the heat distribution in the furnace hearth more uniform.

VI—INDUSTRIAL APPLICATIONS

It is very important to consider to what extent the results obtained from the experiments with the Maerz port on the model furnace can be applied to practice. The ordinary Maerz block is already employed in a few melting shops, but there are not many examples of its use. Where it is used, it is said to give very good results, but it is evident that these are not sufficiently outstanding to bring about a widespread change to the Maerz block. This is in agreement with the results of the experimental furnace, where the unmodified Maerz block (port design No. 3) was shown to be somewhat better than the ordinary block (port design No. 1), but not outstandingly so.

The most important consideration is whether the designs which have given the best experimental results (port designs Nos. 6, 7, and 8) can be applied. There seems to be no reason why a single air uptake as in port designs 6 and 7 should not be used in normal practice. The dimensions of this uptake can be calculated by the standard methods used in furnace design.* Admittedly the design of the brickwork at the lower end of the single uptake requires care, and the furnace steelwork (particularly the bath-supporting girders) may need some change from conventional practice, but these aspects do not present serious difficulty. The use of twin gas ports is still not regarded with favour by many melting-shop managers on account of doubts concerning main-

* *See*, for instance, "The Efficient Use of Fuel," p. 187. London, 1944 : H.M. Stationery Office.

tenance, but an industrial trial of port design No. 7 is being arranged, and it is hoped that a production furnace with this port design will be in operation shortly.*

Heat transfers obtained with port design No. 8 were far higher than in other designs. Construction of this block in the experimental furnace was quite an easy task, but obviously such a construction would present problems in a melting furnace. A tentative suggestion of how this block could be applied to melting furnaces is shown in Fig. 10. By the appropriate use of water cooling at the ports and possibly at the bridge between the air and gas uptakes a sound block should be obtained which would withstand any combustion that would take place within the block. The whole block could be made a removable type. The actual dimensions of the ports depend on the capacity of the furnace and the volumes of air, gas, and waste gases to be handled. These dimensions may be calculated from the normal formulæ, and it should be possible to make the area of the " throat " at the exit from the air port (carrying both incoming gas and air) sufficiently large to accommodate the maximum quantity of waste gases (when on waste gas) without serious sacrifice of efficiency. The melting chamber itself may be of the normal design with or without a sloping back wall.

All the blocks investigated could be utilized in a " one-way " furnace. This would be particularly desirable in the case of port design No. 8, since the rapid-combustion features of this block need not be altered to accommodate exhaust gases.

As regards operation, the putting into practice of the conclusions reached depends largely on adequate provision of instruments, and the importance of this cannot be stressed sufficiently. Although the experimental work suggests the use of theoretical air as a prime desideratum, two practical considerations, namely (*a*) the air unavoidably taken for oxidation of the charge and (*b*) the fact that under some circumstances it is possible, by the use of excess air, to obtain a slightly higher heat transfer to the hearth for a given roof temperature, may make the use of some excess air permissible in practice (*see* Part IV). Similarly the attainment of the desirable high pressure within the melting chamber is governed by the extent of water cooling of the doors and frames and by the standard of maintenance, quite apart from pressure. Thus further study of the extent to which the conditions specified by the experimental work can be implemented in practice depends largely on the extension of instrumentation applied to production furnaces.

VII—CONCLUSIONS

Apart from the study of roof temperature, which is discussed separately in Part IV, the following three main conclusions may be drawn from the experimental work done during the campaign here described :

(1) With the Maerz and modified designs the effects of changes in air/gas ratio and furnace-roof pressure are very similar to those observed with the conventional furnace design used in the work described in Part II. Excess air and low roof pressure both have the effect of diminishing the heat transfer to the hearth for a given heat input to the furnace.

(2) The Maerz port design is less sensitive to gas-port size, *i.e.*, whilst the use of a small gas port (high gas velocity) is advantageous with the normal type of port, in which the air is brought in above the gas and at a slight angle to it, in the Maerz design the gas and air enter the furnace chamber at approximately 90° to each other, so that mixing is less dependent on velocity. It follows that a Maerz or similar design is to be particularly favoured where the available gas pressure is low and it is not possible to use high gas velocities.

(3) The Maerz type of port as normally built in this country and in Europe appears to give slightly, but not outstandingly, better results than the "ordinary" port. Various modifications to the Maerz port have been tried, and one or two of these give outstandingly good results. It must be emphasized, however, that the results described are those obtained from the experimental unit, and that the adaptation of these modifications to production furnaces demands careful study of the conditions obtaining in the particular works concerned, as the dimensions and method of construction used require individual calculation in each case.

(4) The experiments here described have been conducted with producer-gas or mixed-gas-fired furnaces previously in mind. Nevertheless there is every reason to believe that the good results obtained with these special Maerz ports will also be obtained with oil-fired furnaces modified in a similar way.

Acknowledgments

The authors desire to record their thanks to Mr. J. R. Hall, Mr. C. Cartlidge, and the management of the Shelton Iron, Steel and Coal Co., Ltd., for continued provision of facilities for the work ; to Mr. E. D. H. Booth for assistance with the experimental work, and to Dr. A. H. Leckie for advice and encouragement throughout.

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* Since the time of writing, a furnace with this design of port has been successfully operated by Mr. S. W. Pearson and his colleagues at the Rotherham melting shop of Messrs. Steel, Peech and Tozer. A number of oil-fired furnaces have also been rebuilt on rather similar lines, with advantage to operation and without special difficulties arising.

Part IV—THE STUDY OF ROOF TEMPERATURES

By J. H. Cook, B.Sc., and A. H. Leckie, Ph.D., F.R.I.C.

SYNOPSIS

The influence of furnace operating conditions and port design on average and maximum roof temperature was studied. It was found that there was a close link between roof temperature and heat transfer to the hearth, and little can be done (within the framework of one particular design of working chamber) to alter conditions so as to give a higher heat transfer to the hearth without a higher roof temperature. The use of excess air may bring about this effect to a slight extent, but the fuel consumption is substantially increased thereby.

An effective way of increasing heat transfer to the hearth, without damage to the roof, is to increase the uniformity of roof temperature. Various modifications of port design to improve the degree of uniformity are discussed.

In Parts I,[1] II,[2] and III[3] of this series of papers the effect of numerous design and operation variables on the proportion of the heat entering the furnace which is usefully transferred to the hearth has been studied. The main objective has been the ascertaining of the conditions giving the maximum heat transfer to the hearth. In this work little attention was paid to roof temperature, which was allowed to rise to whatever value corresponded to any particular set of operating conditions. This entailed no risk to the furnace structure, as, for reasons already discussed (Part I), the furnace was run at temperatures appreciably lower than those of the steelmaking process. In this way much information upon the effect of furnace operation and design on heat transfer to the hearth has been obtained, but there is always uncertainty as to whether some of the conditions found to give very favourable results in the experimental furnace could be applied in practice owing to overheating of the roof.

From the very beginning of experimental work with the model furnace it had been intended that roof temperatures should be recorded and that a full picture of the roof-temperature distribution should be obtained and interpreted for every experiment. Early trouble with the maintenance of the thermocouples used prevented this complete picture being obtained for the experimental programme described in Part II, although some results were outlined therein. Before the campaign with the Maerz port, described in Part III, was commenced, however, sufficiently robust thermocouples were obtained, so that for that campaign a more complete picture of roof temperature was achieved for each run. This has permitted a proper consideration of roof temperature in relation to heat transfer to the bath, and the present paper is a discussion of these results and an assessment of how they affect the conclusions previously reached from the sole standpoint of maximum heat transfer to the hearth.

EXPERIMENTAL OBJECTIVES AND PROCEDURE

The main objective of the work described in previous Parts was to determine the conditions giving high heat transfers to the hearth with, preferably, relatively low fuel input rates. The work here described has as its objectives the determining of conditions giving high heat transfers to the hearth with, as far as is possible, low roof temperatures. The governing roof temperature is normally the maximum reached at any point in the roof, but other parameters of almost equal importance are the average roof temperature and the degree of uniformity of the roof temperature. It is clearly preferable to have the whole roof at a uniform temperature a few degrees below the permitted maximum rather than have a small area of roof at the maximum permitted temperature and the rest of the roof relatively cold.

The experimental procedure was that described in Part I. Although, as mentioned previously, the thermocouples referred to there failed to withstand the working conditions, the only modification found necessary was the use of heat-resisting steel in place of mild steel for the thermocouple sheaths and the use of stouter thermocouple wires, so that the set-up illustrated in Part I was fundamentally unaltered. Thermocouples were used as the method of temperature measurement because the temperatures encountered were well within the range of robust base-metal thermocouples; in any case, it would have been extremely difficult to insert a sufficient number of

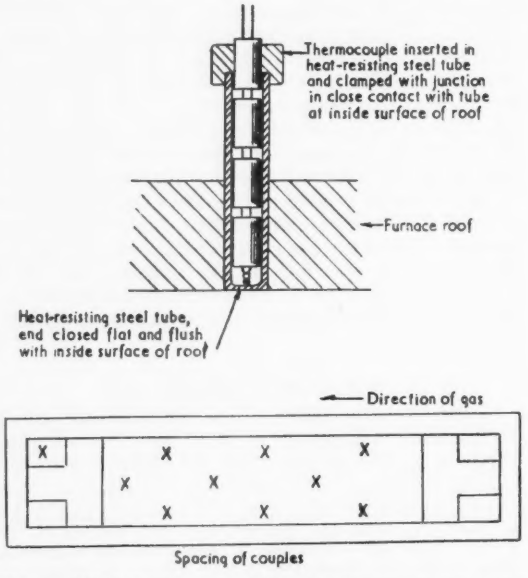
Thermocouple inserted in heat-resisting steel tube and clamped with junction in close contact with tube at inside surface of roof
Furnace roof
Heat-resisting steel tube, end closed flat and flush with inside surface of roof
Direction of gas
Spacing of couples

Fig. 1—Method of insertion of roof thermocouples and spacing of couples in roof

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radiation or photo-electric pyrometers through the side walls of the furnace. The comparison test against a total-radiation pyrometer, described in Part I, showed that the thermocouples gave an accurate measure of the inner surface temperature of the roof. The method of inserting the thermocouples and their positions in the roof of the furnace are shown in Fig. 1. These positions were chosen after consultation with practical furnace operators as to the most vulnerable area of the roof.

For each run the ten values for the steady temperature recorded by each thermocouple were obtained and were recorded on a plan. Ten points were not, of course, a sufficient number to enable a true mosaic or contour map of the roof temperature to be constructed, and for the purposes of the investigation certain quantities calculated from the ten individual readings were used. These quantities were as follows :

(1) Maximum roof temperature (T_m). This quantity is that which governs the rate of operation of the furnace, as it is clear that in practice no furnace can be operated for long with any part of the roof above the maximum safe temperature, irrespective of the temperature of other parts of the roof. In the present series of experiments T_m was taken as the highest reading recorded among the ten points, although it is appreciated that higher temperatures may be reached locally at points not covered by the thermocouples.

(2) Average roof temperature (T_a). This quantity is that which is most closely linked with flame development and heat transfer to the bath. It has been calculated here as the arithmetic mean of the ten points measured, although it is recognized that, owing to the somewhat non-uniform distribution of the thermocouples over the roof, this will not be the true mean temperature. Owing to the importance of heat transfer by radiation it is possible that a better expression for the mean temperature of the ten couples would be :

$$\left[\frac{\Sigma(273 + T)^4}{10}\right]^{\frac{1}{4}},$$

but for the purpose of the present experiments the simpler arithmetic mean is considered adequate.

(3) The range (R). This is the difference between the maximum and minimum steady temperatures recorded during any run and is a measure of the uniformity of roof temperature. In the early stages of the present work more elaborate expressions, such as the " standard deviation," were used as a measure of the uniformity of roof temperature, but it was soon found that expressions of this kind, which are relatively laborious to calculate, offered no practical advantage.

The above three measures of roof temperature are not entirely independent, as, for instance, a low range of temperature in conjunction with a high maximum temperature must mean a high average.

The maximum roof temperature sets a limit to the furnace performance, and the conditions giving maximum heat transfer to the bath for a given safe maximum roof temperature have to be determined. A reasonable expectation is that such maximum transfer would take place when the range was least, but this has to be proved.

Before consideration of the actual experimental results it is necessary to assess the particular roof temperature in the low-temperature experimental furnace which corresponds to the " danger point " (generally regarded as 1640–1680° C.) in a production furnace. This temperature may be termed the " equivalent safe temperature."

General questions of similarity between the low-temperature model and a high-temperature production furnace have already been discussed in Part I, where the " Thring number "[4] was used as a dimensionless criterion of thermal similarity. If this criterion is used, substituting roof temperature for flame temperature (*i.e.*, assuming that the principal interchange of heat is by radiation between roof and hearth), the roof temperature equivalent to 1680° can be calculated as approximately 950° C. However, the applicability of this dimensionless number in this connection is somewhat dubious, and it is perhaps preferable to assess the equivalent safe roof temperature in an arbitrary manner. Conclusions may then be drawn from two different estimates of equivalent safe roof temperature and then compared to see if the estimate is at all critical. This is done later (Table I), assuming temperatures of 900° and 950° C., and it appears that no precise knowledge of equivalent safe roof temperature is needed and that the assumption of 950° C. leads to no serious error in the conclusions drawn. The port design and conditions giving the highest heat transfer to the hearth with a roof temperature of 950° C. would be almost certain to do this over a considerable temperature range on either side.

EXPERIMENTAL RESULTS

The plotting of the experimental results presents some difficulty, as the following three prime factors are involved :

(*a*) The heat input to the furnace.
(*b*) The heat transferred to the hearth.
(*c*) The roof temperature.

The objective is the determination of the conditions giving the most favourable combination of these three prime factors. Just as it would be of little use in practice to establish conditions giving a high heat transfer to the hearth with a relatively low total-heat input to the furnace if the roof temperature greatly exceeds the safe limits with such conditions, it would also be of little practical interest if a high heat transfer to the hearth with a low roof temperature was made possible by artificial cooling of the roof in such a way that the fuel consumption of the furnace became excessive.

The first step is clearly a study of how the maximum roof temperature and the range of roof temperature vary with (*a*) rate of heat input, *i.e.*, gas flow, (*b*) air/gas ratio, (*c*) furnace pressure, and (*d*) port design. These are illustrated in Figs. 2 and 3, Fig. 2 showing the variation of maximum roof temperature and range of roof temperature with heat input, *i.e.*, gas rate, for various air/gas ratios and port designs, and Fig. 3 showing the variations with furnace pressure and port design.

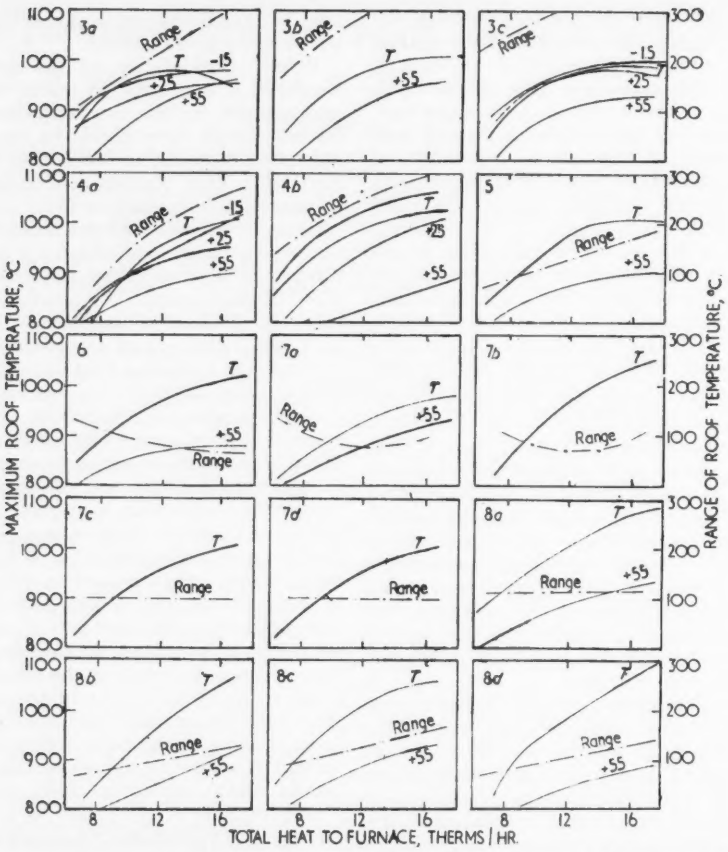

Fig. 2—Variation of maximum roof temperatures and range with heat input (Maerz port and modifications). The figures in the top left-hand corners refer to port design numbers (*see* Table I of Part III); the figures on the curves denote percentage excess or deficient air (*T* = theoretical). Furnace pressure 0·02 in. W.G.

The first obvious conclusion from Figs. 2 and 3, when studied in conjunction with similar data for heat transfer to the hearth (Fig. 3 of Part III), is that roof temperature increased with heat input and furnace pressure in very much the same way as the heat transfer to the bath. In other words, under most conditions it is not possible to increase the amount of heat transferred to the hearth without increasing the roof temperature at the same time. Since there is a maximum safe roof temperature this at once sets a limit to the performance of the furnace.

Effect of Gas Rate

As might be expected, increasing the gas rate increases the maximum roof temperature in very much the same way as it increases the heat transfer to the hearth (*see* Fig. 3 of Part III and Fig. I of Part II). This similarity also extends to the few cases of inefficient combustion conditions in which the heating of the furnace is decreased at maximum gas rates owing to excess unburnt gas carrying heat away from the combustion chamber.

In port designs Nos. 3 to 5 the range increases rapidly with gas rate. As the quantity of gas used is increased, the flame lengthens and the heat release is increased, so that the temperature at the outgoing end is naturally raised. With these port designs, however, the efficiency of mixing (of gas and air) is not sufficiently high to cause a corresponding rise of temperature at the ingoing end, so that the temperature variation along the length of the roof is increased.

The more efficient port designs do not exhibit such a pronounced increase of range at the higher gas rates, as combustion is developed sufficiently early along the flame to increase appreciably the roof temperature at the incoming end as the gas flow is increased. In fact, with some port designs and low gas flow the roof at the ingoing end is hotter than at the outgoing end.

Effect of Air/Gas Ratio

The effect of excess air in cooling the furnace is shown when roof temperature is studied in just the same way as when heat transfer to the hearth is made the dependent variable.

Only one line representing range is drawn in Fig. 2, as in nearly all cases the range was not appreciably affected by air/gas ratio. In Fig. 16 of Part II the range is greater at high air/gas ratios, but this effect was not observed to any extent in the present tests.

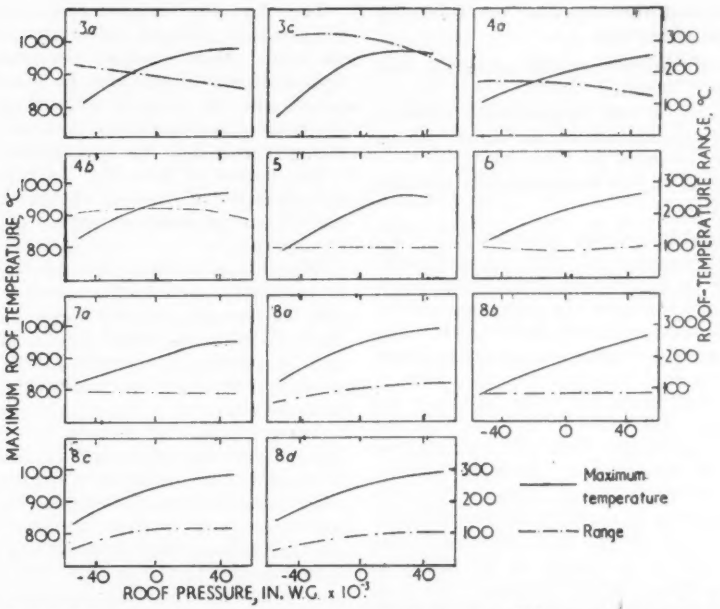

Fig. 3—Variation of maximum roof temperatures with roof pressure (Maerz ports and modifications). The figures in the top left-hand corners refer to port design numbers. Air/gas ratio—theoretical

Effect of Port Design

Port designs giving a high heat transfer to the hearth also gave relatively high maximum roof temperature, but, as mentioned above, the more efficient designs give a lower range at the higher heat inputs.

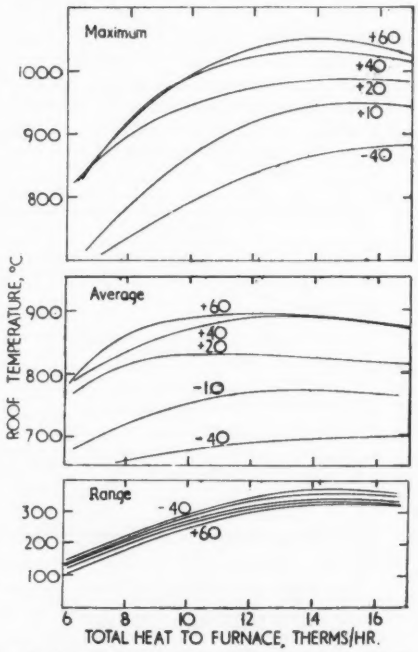

Fig. 4—Variation of roof temperature with heat input at various roof pressures. The figures on the curves denote roof pressure (thousandths of an inch water gauge)

Effect of Furnace Pressure

In Part II (Fig. 18 of that Part) it was suggested that the use of relatively high pressures in the operating chamber might be a method of preventing the roof temperature from rising at increased gas rates giving higher heat transfer to the hearth. This suggestion was made only tentatively because few observations were available at that time. The present Fig. 3, which gives the results of a large number of investigations in which furnace pressure was made the main variable, does not consistently confirm the earlier observation, though there are a few examples of the roof temperature not rising appreciably at maximum pressure. However, the data in Fig. 3 are, of course, obtained with a different block design from that dealt with in Part II.

In general, the effect of increased furnace pressure is to raise the roof temperature and the heat transfer to the hearth for a given heat input. A group of characteristic curves connecting maximum roof temperature and total heat input to the furnace for various pressures is given in Fig. 4.

The range of temperature between the ingoing and outgoing ends is not appreciably affected by furnace pressure, although it is somewhat diminished by high pressure in the case of the less efficient port designs.

Uniformity of Roof Temperature

The effect of operating variables on the range of roof temperature has been briefly outlined above. The maintenance of roof temperature at a high and *uniform* level is, however, of such importance in efficient steel melting that the subject merits further

study. In the present investigation the following three quantities are of interest :

(*a*) The range of roof temperature along the roof (already discussed), denoted by R.

(*b*) The difference in roof temperature between the outgoing and ingoing ends of the furnace (along the central axis), denoted by $(T_o - T_i)$.

(*c*) The variation of roof temperature across the furnace, denoted by A.

In the experimental furnace the quantity $(T_o - T_i)$ is greatly exaggerated compared with ordinary melting furnaces because the experimental furnace is not reversed. This does not diminish the importance of the information to be gained from this quantity, as the conditions obtained in a non-reversing furnace are incipient in reversing furnaces fired from one end at a time.

Under many circumstances the value of $(T_o - T_i)$ is little different from the value of R, since the roof temperature rises continually from the incoming to the outgoing end of the furnace. Nevertheless the study of the separate quantities is necessary, because under certain conditions of early flame development within the lower range of gas flows the maximum release of heat occurs in the middle of the flame, so that the roof temperature at the incoming and outgoing ends of the furnace are about the same ($T_o - T_i$ equals zero), the difference between the roof temperature at the middle and at the ends of the furnace being sufficient to give an appreciable value of R.

Under what might be called " normal " conditions, the range R increases as the heat input increases, but the range is much diminished with ports giving good mixing. The reason for this has already been explained under the sub-heading " Effect of Gas Rate." However, the slope and shape of the curves in which the roof-temperature range is plotted against heat input to the furnace can vary quite considerably (as is evident in Fig. 2). This can perhaps best be expressed mathematically* as follows, where R = roof-temperature range, h = total heat to furnace, T_i = roof temperature at incoming end, and T_o = roof temperature at outgoing end :

$\frac{dR}{dh}$ is positive :

(*a*) If $T_o > T_i$ and $\frac{dT_o}{dh} > \frac{dT_i}{dh}$.

(*b*) If $T_o < T_i$ and $\frac{dT_o}{dh} < \frac{dT_i}{dh}$.

$\frac{dR}{dh}$ is negative :

(*c*) If $T_o > T_i$ and $\frac{dT_o}{dh} < \frac{dT_i}{dh}$.

(*d*) If $T_o < T_i$ and $\frac{dT_o}{dh} > \frac{dT_i}{dh}$.

$\frac{dR}{dh}$ is zero (*i.e.*, R is constant) :

(*e*) If $\frac{dT_o}{dh} = \frac{dT_i}{dh}$

These are the simplest cases, applying if the roof temperature changes uniformly along the length of the roof. More complex conditions giving various values of dR/dh can also be visualized, *e.g.*, dR/dh would also be zero, if $(dT_o/dh) \neq (dT_i/dh)$. if the positions of maximum and minimum roof temperature changed with R in the appropriate way.

The curves of R in Fig. 2 for port designs 3 to 5 are examples of case (*a*) above. Port designs 6, 7*a*, and 7*b* are probably examples of case (*d*) changing to case (*a*).

With these ports at low gas flow $T_o < T_i$ (owing to relatively good mixing), and it may be assumed that as the gas rate increases $(dT_o/dh) > (dT_i/dh)$. Thus T_o becomes equal to T_i, and, with ports 7*a* and 7*b*, eventually exceeds T_i, so that the direction of slope of the range curve changed (case (*d*) changing to case (*a*)).

Ports 7*c*, 7*d*, and 8 have low values of R and of $T_o - T_i$, the sign of the latter changing as h increases. The point of maximum roof temperature varies somewhat with these port designs, and this explains the low value and relative uniformity of R. This is another reason why these port designs give efficient heat transfer to the hearth—the point of maximum roof temperature is not at the end of the furnace and thus can subtend a greater angle at the hearth.

Ports 8*b* to 8*d* are again examples of case (*a*), but the variations are on a much reduced scale owing to the relative efficiency of the port design. The actual value of R is slightly increased, since this type of block tends to shield the roof at the incoming end, so reducing T_i.

Variation of Roof Temperature across the Furnace

With regard to the variation of roof temperature across the furnace (A) the general tendency was for the mean roof temperature along the back wall to be higher than that near the front wall. This difference was about 40° C. with the less efficient variations of the Maerz ports, almost zero with the better types

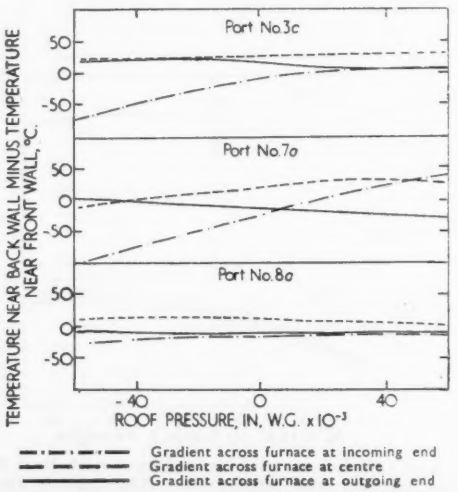

Fig. 5—Variation of temperature gradient across furnace with roof pressure

* For reasons of clarity and economy in wording, it is convenient here to use calculus notation. For readers unfamiliar with this it should be stated that dR/dh means the " rate of change of R with respect to h." If R increases as h increases, dR/dh is positive ; if R decreases as h increases dR/dh is negative. Similarly, dT/dh is a measure of how T changes with h.

of port, and with the most efficient designs, such as port design No. 8, for example, the roof near the back wall tended to be cooler than that near the front wall. The temperature along the central (longitudinal) axis tended to be higher than that along the walls ; this effect was more pronounced with the less efficient ports, such as No. 3, than with the more efficient, such as No. 8.

Theoretically, with a central and symmetrical disposition of flame in the furnace there should be little difference between the front and back roof temperatures, but the difference found with the experimental furnace is also found in production furnaces, where the roof often tends to wear to a greater extent towards the back wall. On the assumption that the most likely cause of temperature asymmetry was infiltration through the door, the effect of varying furnace pressure on this asymmetry was investigated. Typical curves are shown in Fig. 5. The only pronounced exception to the general tendency for roof temperature to rise towards the back wall is at the ingoing end of the furnace when operating under low furnace pressures, when the roof temperature near the front wall is hotter than that near the back wall. This particular phenomenon disappears as soon as the furnace pressure is increased.

The variation of roof temperature across the furnace in the above experimental observations can be explained as being due to air infiltration. Normally, air infiltration cools the hearth along the front wall (in practice this is occasionally observed by slag freezing along the front sill when operating with too high a draught), and this results in a greater radiation from roof and flame to hearth in this position. At the incoming end, when operating under excessive draught, the volume of infiltrated air may be sufficient to give accelerated combustion along the flame surface nearest to the door, so providing a tendency for this side of the furnace to be hotter at the incoming end. If this view is true the effect should be more marked with the less efficient port designs, and Fig. 5 shows this to be the case.

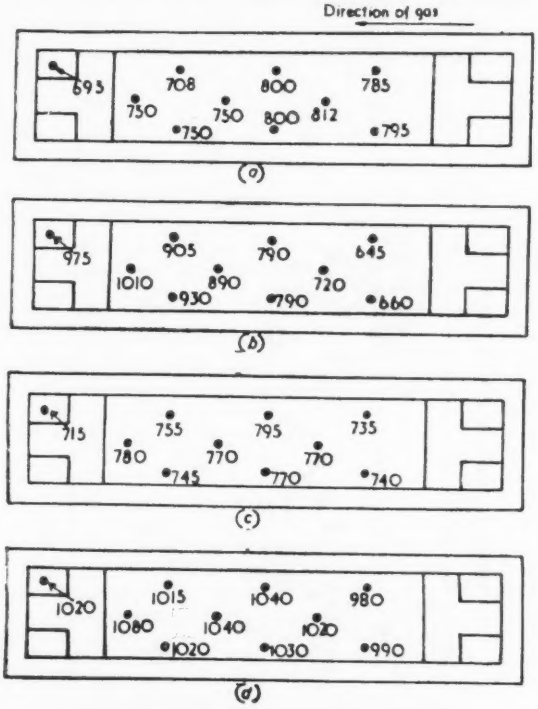

Fig. 6—Typical roof-temperature distributions (°C.): (*a*) Low gas flow, early flame development (run No. 340, port 7*d*); (*b*) high gas flow, late flame development (run No. 134, port 3*b*); (*c*) low gas flow, uniform roof temperature (run No. 367, port 8*d*); (*d*) high gas flow, uniform roof temperature (run No. 436, port 8*a*)

Variation of Roof Temperature along the Furnace

As might be expected in a " one-way " furnace, the roof at the incoming end tended to be cooler than that at the outgoing end. However, with the more efficient types of port, giving early combustion, the middle of the roof tended to be hottest when low gas flows were used, but as soon as full gas was put on the flame lengthened sufficiently to produce the hottest part of the roof at the outgoing end again.

It should be emphasized, however, that in many cases the temperature gradient along the roof was not great, and several of the better port designs, such as port design No. 8, gave a remarkably uniform temperature along the roof for a one-way furnace.

Space does not permit of the reproduction of the several hundred charts of roof-temperature distribution which have been obtained, but some typical examples are given in Fig. 6.

The effect of excess air is to bring the hot zone slightly towards the incoming end of the furnace (owing to the tendency for excess air to speed up combustion), though the general level of roof temperature is reduced by this excess air.

Direct Correlation of Average Roof Temperature and Heat Transfer to the Hearth

Much of the foregoing discussion refers to maximum roof temperature, this being the quantity which limits the rate of fuel input. Nevertheless, the quantity most closely governing heat transfer to the hearth is average roof temperature, and, whilst it has been stated previously that the true effective average is not likely to be the arithmetic mean of the ten measured points, the arithmetic mean is in sufficiently close approximation to the more complex mean which the exact radiation equations would require. When the heat transfer to the hearth was plotted against average roof temperature for all port designs, all the curves lay close together and were intermingled. It was evident that no port design showed any particular advantage as regards obtaining a high heat transfer to the hearth for a given average roof temperature, and Fig. 7 shows plots of some results for heat transfer to the hearth and average roof temperature for theoretical air and for 55% excess air. There is a slight indication that excess air may permit higher heat transfer to the hearth for a given roof temperature, but it is very doubtful whether this is statistically significant in view of the general scatter. The close connection between roof temperature and useful heat

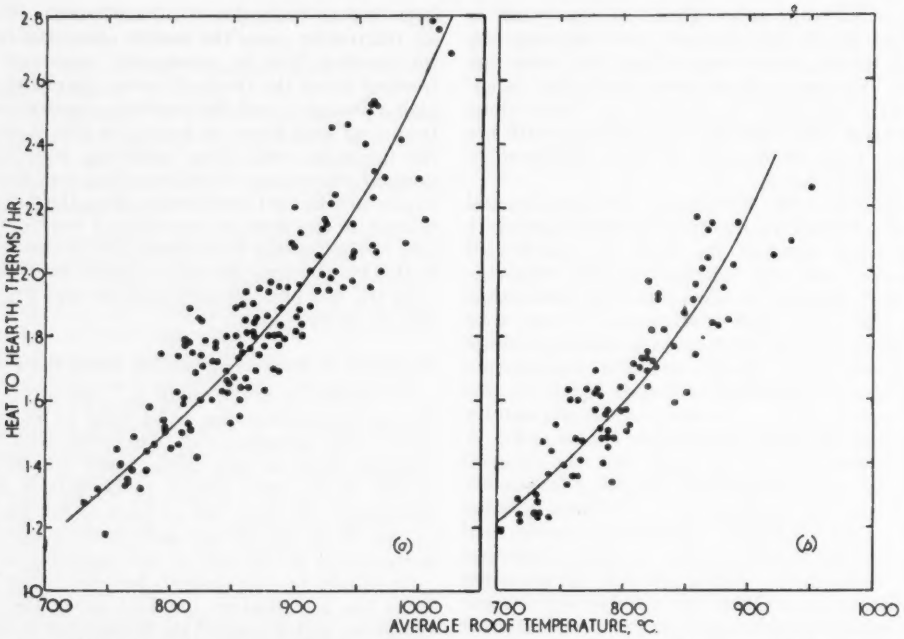

Fig. 7—Relationship between heat transfer to hearth and average roof temperature. Individual experimental points for ports 5–8 : (*a*) Theoretical air ; (*b*) 55% excess air. Furnace pressure + 0·02 in. W.G.

transfer is also shown in Fig. 7, and the diagrams stress the importance of roof-temperature determination as a measure of speed of furnace working. Land[5] has shown that the scatter in Fig. 7 can be greatly reduced by applying a correction for convection (based on gas velocity and air/gas ratio) to each experimental point.

When the curves for individual port designs were being plotted, a few curves for port design No. 3 showed a bending-over effect, in which there was a return to lower roof temperatures at high heat transfers to the hearth. This reflects the effect of unburnt gas passing out of the furnace (Fig. 3 of Part III), and this unburnt gas appears to have a cooling effect on the roof (*cf.* excess air below) giving a higher heat transfer for a given roof temperature, at the expense of fuel consumption.

DISCUSSION OF RESULTS

One of the first objectives of the present work is to determine the conditions giving the highest heat transfer to the hearth without exceeding the equivalent safe roof temperature, which has previously been estimated to be 950° C. Since the highest heat transfers to the hearth are all associated with roof temperatures well in excess of 950° C., the interpretation of the data is somewhat complex, since the ultimate objective is a high heat transfer to the hearth with a relatively low heat input, while not exceeding the safe roof temperature.

Since, as far as is known, neither the characteristic curves of heat transfer to the bath nor of roof temperature conform to any simple mathematical form, the problem does not lend itself to interpretation by means of complex polydimensional diagrams, and it

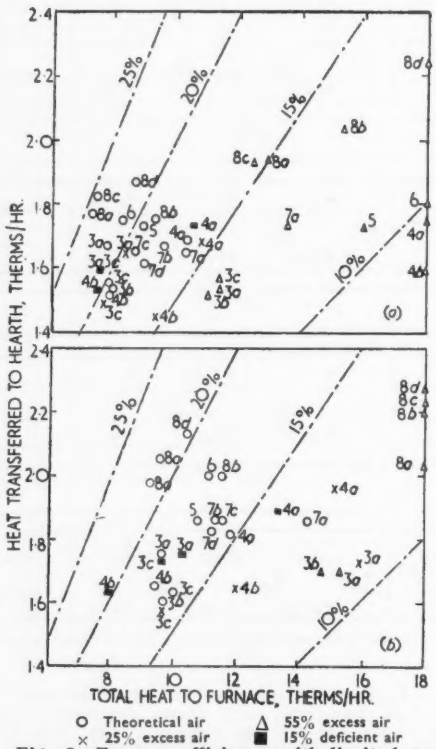

Fig. 8—Furnace efficiency with limited roof temperatures for various port designs: (*a*) Maximum roof temperature 900° C.; (*b*) maximum roof temperature 950° C.

Table I

Roof not Exceeding 900° C.				Roof not Exceeding 950° C.			
Port Design No.	Excess Air, %	Heat Transfer to Hearth, therms/hr.	Total Heat to Furnace, therms/hr.	Port Design No.	Excess Air, %	Heat Transfer to Hearth, therms/hr.	Total Heat to Furnace, therms/hr.
8*d*	+55	2·23*	18·0	8*d*	+55	2·28*	Over 18
8*b*	+55	2·04	15·4	8*c*	+55	2·23	Over 18
8*a*	+55	1·94	12·9	8*b*	+55	2·20	Over 18
8*c*	+55	1·93	12·5	8*d*	0	2·13	10·5
8*d*	0	1·87	8·8	8*a*	0	2·07	9·6
8*c*	0	1·82	7·6	8*a*	+55	2·03	Over 18
6	+55	1·80	Over 18	6	0	2·0	11·1
8*a*	0	1·77	7·3	8*b*	0	2·0	11·4
8*b*	0	1·76	9·4	8*c*	0	1·98	9·3
4*a*	+55	1·76	18·0	4*a*	+25	1·96	15·1
6	0	1·75	8·3	4*a*	−15	1·88	13·3
5	+55	1·74	16·0	7*b*	0	1·86	11·4
5	0	1·73	8·9	7*c*	0	1·86	11·6
4*a*	−15	1·73	10·6	7*a*	0	1·86	14·3
7*a*	+55	1·73	13·7	5	0	1·85	10·8
4*a*	0	1·69	10·2	7*d*	0	1·82	11·2
4*a*	+25	1·68	10·7	4*a*	0	1·81	11·8
3*a*	0	1·67	7·8	3*a*	0	1·76	9·6
7*b*	0	1·67	9·6	3*a*	−15	1·76	10·3
3*a*	+25	1·65	8·3	3*c*	−15	1·73	9·7
7*c*	0	1·65	8·7	3*a*	+25	1·72	16·0
7*a*	0	1·65	10·4	3*b*	+55	1·70	14·7
7*d*	0	1·61	9·0	3*a*	+55	1·70	14·7
7*d*	0	1·61	9·0	3*a*	+55	1·70	15·3
4*b*	+55	1·60	Over 18	4*b*	0	1·66	9·4
3*a*	−15	1·59	7·5	4*b*	+25	1·65	12·0
3*c*	−15	1·59	7·6	3*c*	0	1·64	10·0
3*c*	+55	1·57	11·2	4*b*	−15	1·63	8·3
3*c*	0	1·55	7·9	3*b*	0	1·60	9·8
3*a*	+55	1·55	11·3	3*c*	+25	1·59	9·7
4*b*	−15	1·53	7·2				
3*b*	0	1·53	8·0				
4*b*	0	1·57	7·8				
3*b*	+55	1·51	11·0				
3*c*	+25	1·49	7·7				
4*b*	+25	1·44	9·4				

*These figures are averages for these particular port designs and conditions of operating. Figure 7, as a scatter diagram, shows individual experiments where these average values have been exceeded on occasion.

seemed simplest to study the problem by preparing an elementary statement such as Table I. This was prepared by drawing lines at the 900° and 950° C. level across all the graphs in Fig. 2 and determining what heat input to the furnace gave these maximum roof temperatures. The corresponding heat transfer to the hearth was then obtained from Fig. 3 of Part III.

The information given in Table I is portrayed graphically in Fig. 8. The experimental results fall naturally into two groups, the theoretical-air group and the 55% excess-air group.

Effect of Excess Air

The main conclusion to be drawn from Table I and Figs. 7 and 8 is that when the limitations imposed by roof temperature are taken into account, under some conditions there may be a distinct advantage in working with excess air. This is an apparent reversal of the recommendation made in previous Parts of the series, in which the use of theoretical air was recommended, but a clear distinction has to be drawn between the air/gas ratio which gives the maximum heat transfer to the hearth irrespective of roof temperature and that which gives the maximum heat transfer to the hearth for a specified roof temperature. When roof temperature is limited the highest heat transfers to the hearth may occasionally be obtained with the use of appreciable excess air, but it must be emphasized that this is at the cost of a greatly increased fuel consumption.

Table I also shows that with theoretical air the maximum heat transfer to the hearth which is obtainable within the range of experiments tried, and without exceeding the equivalent safe roof temperature of 950° C., is 2·13 therms per hour, which requires a total heat input to the furnace of 10·5 therms per hour. By the use of excess air it was possible to increase the heat transfer to the hearth to 2·28 therms per hour (an increase of 7%), but this needed an increase of fuel input to over 18 therms per hour (roughly an additional 75%). This indicates that the final few units of output rate which it is possible to obtain in any furnace must be purchased at a very high cost in fuel. It is interesting to observe that the results are similar whether 950° or 900° C. is taken as the maximum roof temperature; this implies that an exact assessment of the equivalent safe roof temperature in the model furnace is of less importance.

The theory of heat transfer within the melting chamber of an open-hearth furnace has been studied intensively by Thring[6] and by Land.[5] These investigators have considered heat transfer by radiation only, as calculation by means of the ordinary heat-

transmission equations[7] shows that at the high operating temperatures of an open-hearth furnace convective heat transfer is only a few per cent of the total.* This theoretical work, which arose from experimental observations made on production furnaces, suggests a number of methods by which heat transfer to the hearth may be increased without overheating of the roof. These are as follows :

(1) By increasing the flame temperature and decreasing its emissivity.

(2) By interposing a relatively cool and opaque gas layer between the flame and the roof, thereby decreasing the heat transfer between flame and roof.

(3) By interposing a moving layer of cooler air or gas between flame and roof, thus cooling the roof by convection.

(4) By increasing the heat losses from the roof (generally by increasing its distance from the flame and by increasing its area).

In considering the present experimental results in the light of the above propositions, we are not concerned with method (4), since the geometry of the main furnace chamber remained unchanged throughout the experiments here described, only the ports being altered. The remaining propositions are, however, well in line with the present experimental observations, as follows :

(*a*) Under conditions of equal air/gas ratios, the port designs giving better mixing also give higher heat transfer to the hearth without exceeding the equivalent safe roof temperature and, probably, a lower-emissivity flame owing to the improved combustion. Thus the experimental result is in accordance with proposition (1).

(*b*) The finding that the heat transfer to the hearth for a given roof temperature tends to be improved by excess air agrees with propositions (2) and (3). Thring's calculations suggest that (2) is likely to have a greater effect, *i.e.*, it is better to have a thick stagnant layer of inert but radiation-absorbing atmosphere between the flame and roof than to have a fast-moving stream of lower emissivity.

To a certain extent proposition (1) conflicts with (2) and (3) in that whilst rapid and efficient mixing of gas and air is desirable to give a high flame temperature, if excess air is used to give the conditions leading to cooling of the roof by shielding the roof from the flame, good mixing of this excess air will lead to a lower flame temperature than might arise with less efficient mixing. There would seem to be an argument here for a double system of ports, one being a port design such as No. 8, giving efficient mixing of gas and air and in which theoretical air would be used, and another air port entering below the roof, designed to avoid as far as possible mixing with the flame and through which, say, 50% excess air (if necessary admixed with a little steam to increase absorptivity) would be passed to shield the roof.

This would be adopted only if it was decided on economic grounds that the slight extra output to be obtained would warrant the substantially increased fuel consumption.

Whilst this concept of a cool layer of air or other gas under the roof is widely held, searching experimental proof of its existence is required before it can be accepted. Clearly a cool layer of gas cannot persist *above* a hot layer for any appreciable period, and one would expect mixing to take place at a relatively early stage. Information on this should be forthcoming from the model work recently started by Philip[9] and Newby.[10] It is more probable that shielding of the roof is due to the heat-absorbing properties of the combustion products under the roof.

It may be concluded that whilst the present experiments show some slight indication that excess air may permit higher heat transfer to the hearth for a given roof temperature, and whilst this observation is in agreement with other existing observations and theories, the degree of benefit is slight and its statistical significance is open to question. What can be stated

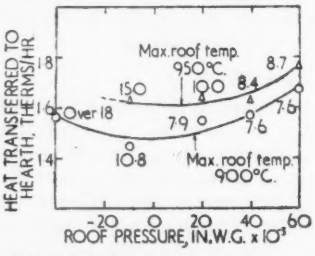

Fig. 9—Effect of roof pressure upon the heat transferred to the hearth for a given maximum roof temperature. Port 3c and theoretical air. The figures against the points denote heat inputs (therms per hour) required to attain the values shown

* There is no doubt at all that under production conditions convection plays a greater part than pure theory would indicate. The " cutting down " of scrap by a hot short flame is well known, and there are also many cases reported from practice where the slag surface temperature is at times hotter than the roof. These phenomena may be explained in a number of ways, *viz.*, (1) direct impingement of flame gives a higher degree of convective heat transfer than normal owing to the removal or diminution of the stagnant gas layer at the surface (see reference 8) ; (2) abnormal turbulence owing to a rough surface also increases the " scrubbing " action ; (3) the actual surface area exposed to convective heat transfer may be many times the nominal hearth area during the earlier stages of melting down. In addition, the view has sometimes been expressed that catalytically assisted combustion may take place on exposed surfaces of the charge, leading to specially efficient heat transfer. However, at the temperature of open-hearth furnaces the combustion reactions are so rapid that combustion may be assumed to take place immediately mixing of gas and air occurs, so that catalysis is not likely to be important. Nevertheless, some sort of surface-assisted heat transfer may well take place, probably by turbulent mixing of stratified gases at the surface, so that any specially efficient heat transfer here may be due to assisted mixing and not to assisted combustion. It is evident that the mechanism of heat transfer in open-hearth furnaces demands further study, and calculations such as those of Thring and Land, whilst affording a most useful beginning for such a study, will need to be vigorously pursued to a much wider extent in order to explain all that is observed in practice.

with more certainty is that the use of excess air may give greater latitude in roof safety (particularly where roof-temperature measuring instruments are absent) and it is this point which is probably the main justification for its moderate use in practice.

Effect of Pressure

The above discussion was concerned mainly with the effect of air/gas ratio and port design on the maximum transfer of heat to the hearth which can be attained whilst not exceeding the maximum safe roof temperature. In this connection furnace pressure has also to be considered, as whilst increasing the furnace pressure assists heat transfer to the hearth, it also increases roof temperature. Sufficient data are not so far available to permit an investigation in such detail as was carried out with air/gas ratio, but Fig. 9 is an indication of the variation of heat transfer to the hearth for a given maximum roof temperature, which may be obtained at various furnace pressures, though this is applicable only to the one port design for which sufficient data are available.

These results are rather striking in that the curves show a minimum ; in other words, the heat transfer to the hearth for a given roof temperature can be increased either by working at a very high roof pressure, with marked economy in fuel consumption,* or at a very low roof pressure (excessive draught) involving high fuel consumption. The explanation of this would appear to be fairly straightforward. At the highest roof pressures, all serious roof infiltration, even at the bottom of the doors, is stopped, so that heat transfer to the hearth is very efficient. At intermediate roof pressures (which probably represent the range of working in practice) there is air infiltration under the doors which, as Land[5] has shown, will disturb heat transfer to the hearth, whilst not preventing heat transfer to the roof. At very low roof pressures there is air infiltration at the top as well as at the bottom of the doors, so that the roof is protected by cool air to an extent which permits increase of heat transfer to the hearth by means of high fuel input.

Thus the position with regard to roof pressure is rather similar to that with excess air, namely, that heat transfer to the hearth for a given roof temperature can be obtained by working the furnace inefficiently so as to cool the roof with excess of infiltrated air. This explains why some furnaces are found to work better with very high draught, particularly when the fuel consumption cannot be checked precisely.

Application in Practice

The extent to which a slight additional output (for a given maximum roof temperature) obtained by using excess air or low roof pressure at the expense of relatively high fuel consumption is economic cannot be decided here. Although the highest air/gas ratio used during the course of the experiments was an excess of 55%, there was no indication that this was the effective limit ; possibly the excess air could be increased considerably above this to give even greater heat transfers to the hearth without exceeding the safe roof temperature. Needless to say, the fuel consumption to attain such a result would be extremely high. Clearly there would be an obvious practical limit to the use of excess air in this way, although the use of the special divided air port suggested earlier in this paper might permit an extension of roof cooling by excess air without unduly excessive fuel consumption. However, the effect would be less marked on a production furnace (using air at 1200° C.) than on the model furnace.

Further study of this problem is of great importance in view of the growing interest in the automatic control of open-hearth-furnace firing. The type of controller which is at present being considered, and which has already been shown to work satisfactorily in practice, is a roof-temperature/fuel-flow link which reduces the fuel supply when the roof temperature approaches the safe maximum. (Incidentally, this is not a simple on-off control, but is perforce a more complex mechanism to prevent " hunting " and to take necessary anticipatory action.)

It would seem reasonable to suggest that additional output might be obtained by linking the roof-temperature controller to the air flow as well as to the fuel flow. When the roof temperature approaches the maximum, the controller would turn on additional air so as to permit the continuance of full fuel flow and so attain maximum heat transfer to the hearth. Some overriding control on fuel flow would be necessary to prevent a " runaway " between air and fuel together. The actual method of control would have to be changed appropriately during a heat, along, for instance, the following scheme.

During charging and the initial stages of melting there is little risk of the roof temperature attaining the maximum safe value, and the air/fuel ratio could be set at theoretical (as recommended in Part II) and the fuel at the maximum rate which the furnace can burn efficiently.

When the charge is partially melted, the roof temperature approaches the danger limit, and from then until the charge is completely melted and the slag " in condition " is the critical period during which maximum heat transfer to the bath is required, yet the roof temperature requires careful watching. During this period more excess air to keep down roof temperature may be permissible, and the controlling mechanism could be changed if possible to control excess air according to roof temperature.

The procedure once the slag is " in condition " would depend on the class of steel being made ; for instance, manufacture of low-carbon steels requires a high heat transfer throughout to permit a high rate of feeding, so that the control on excess air might be continued during the remainder of the charge. With high-carbon steel, " heat " is not such a problem, so that the fuel-economy advantages of a return to theoretical air might be exploited by setting the controller on a roof-temperature/fuel link alone.

The recommendation made in previous papers on this work, namely, that roof pressure should be maintained at as high a level as is consistent with practical working, remains unchanged in the light of the results obtained by the study of roof temperatures.

* Until relatively high roof pressures are attained, the advantages of increased roof pressure are more marked as regards fuel economy rather than increased rate of heat transfer, though both these requirements benefit.

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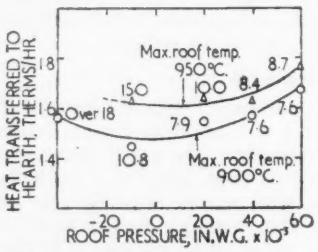

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Thus the position with regard to roof pressure is rather similar to that with excess air, namely, that heat transfer to the hearth for a given roof temperature can be obtained by working the furnace inefficiently so as to cool the roof with excess of infiltrated air. This explains why some furnaces are found to work better with very high draught, particularly when the fuel consumption cannot be checked precisely.

Application in Practice

The extent to which a slight additional output (for a given maximum roof temperature) obtained by using excess air or low roof pressure at the expense of relatively high fuel consumption is economic cannot be decided here. Although the highest air/gas ratio used during the course of the experiments was an excess of 55%, there was no indication that this was the effective limit ; possibly the excess air could be increased considerably above this to give even greater heat transfers to the hearth without exceeding the safe roof temperature. Needless to say, the fuel consumption to attain such a result would be extremely high. Clearly there would be an obvious practical limit to the use of excess air in this way, although the use of the special divided air port suggested earlier in this paper might permit an extension of roof cooling by excess air without unduly excessive fuel consumption. However, the effect would be less marked on a production furnace (using air at 1200° C.) than on the model furnace.

Further study of this problem is of great importance in view of the growing interest in the automatic control of open-hearth-furnace firing. The type of controller which is at present being considered, and which has already been shown to work satisfactorily in practice, is a roof-temperature/fuel-flow link which reduces the fuel supply when the roof temperature approaches the safe maximum. (Incidentally, this is not a simple on-off control, but is perforce a more complex mechanism to prevent " hunting " and to take necessary anticipatory action.)

It would seem reasonable to suggest that additional output might be obtained by linking the roof-temperature controller to the air flow as well as to the fuel flow. When the roof temperature approaches the maximum, the controller would turn on additional air so as to permit the continuance of full fuel flow and so attain maximum heat transfer to the hearth. Some overriding control on fuel flow would be necessary to prevent a " runaway " between air and fuel together. The actual method of control would have to be changed appropriately during a heat, along, for instance, the following scheme.

During charging and the initial stages of melting there is little risk of the roof temperature attaining the maximum safe value, and the air/fuel ratio could be set at theoretical (as recommended in Part II) and the fuel at the maximum rate which the furnace can burn efficiently.

When the charge is partially melted, the roof temperature approaches the danger limit, and from then until the charge is completely melted and the slag " in condition " is the critical period during which maximum heat transfer to the bath is required, yet the roof temperature requires careful watching. During this period more excess air to keep down roof temperature may be permissible, and the controlling mechanism could be changed if possible to control excess air according to roof temperature.

The procedure once the slag is " in condition " would depend on the class of steel being made ; for instance, manufacture of low-carbon steels requires a high heat transfer throughout to permit a high rate of feeding, so that the control on excess air might be continued during the remainder of the charge. With high-carbon steel, " heat " is not such a problem, so that the fuel-economy advantages of a return to theoretical air might be exploited by setting the controller on a roof-temperature/fuel link alone.

The recommendation made in previous papers on this work, namely, that roof pressure should be maintained at as high a level as is consistent with practical working, remains unchanged in the light of the results obtained by the study of roof temperatures.

* Until relatively high roof pressures are attained, the advantages of increased roof pressure are more marked as regards fuel economy rather than increased rate of heat transfer, though both these requirements benefit.

CONCLUSIONS

The conclusions reached regarding roof temperatures may be stated as follows :

(1) As a general rule, increased heat transfers to the hearth are associated with higher roof temperatures. There is a very strong correlation between average roof temperature and heat transfer to the hearth.

(2) In general, very little can be done within the framework of one particular geometrical design of furnace to increase the heat transfer to the hearth for a given *average* roof temperature, apart from the possible use, in some circumstances, of excess air (*see* conclusion (3) below). Heat transfer to the hearth for a given limited *maximum* (local) roof temperature can be improved by improving the uniformity of roof temperature, and this can be done by shortening the flame through the use of more efficient port designs giving more rapid mixing, such as port designs Nos. 7 and 8.

(3) For a given limited roof temperature, a somewhat higher heat transfer to the hearth can sometimes be obtained by the use of appreciable excess air, but at the expense of substantially increased fuel consumption.

(4) Port designs such as Nos. 7 and 8, which give a high heat transfer to the hearth and high roof temperatures, may be expected to be much more flexible in practical operation. Whilst under most conditions their ability to burn fuel rapidly and efficiently is limited by roof-temperature considerations, the ability to reach high rates of heat release is particularly advantageous during the charging period and initial stages of melting, when there is less risk of exceeding the maximum safe roof temperature.

(5) In the case of the Maerz and the modified Maerz designs the port design is of greater importance than the relative size of the gas and air openings.

It must be emphasized that these conclusions on roof temperature have been reached from a study of experimental results from Maerz and modified Maerz furnaces. They are not necessarily applicable to furnaces of other designs, and work now proceeding on a different type of furnace will be reported at a later date.

Acknowledgments

The authors desire to record their continued indebtedness and thanks to the management and melting-shop staff of the Shelton Iron, Steel and Coal Co., Ltd., Stoke-on-Trent, for the constant facilities for, and support of, the research.

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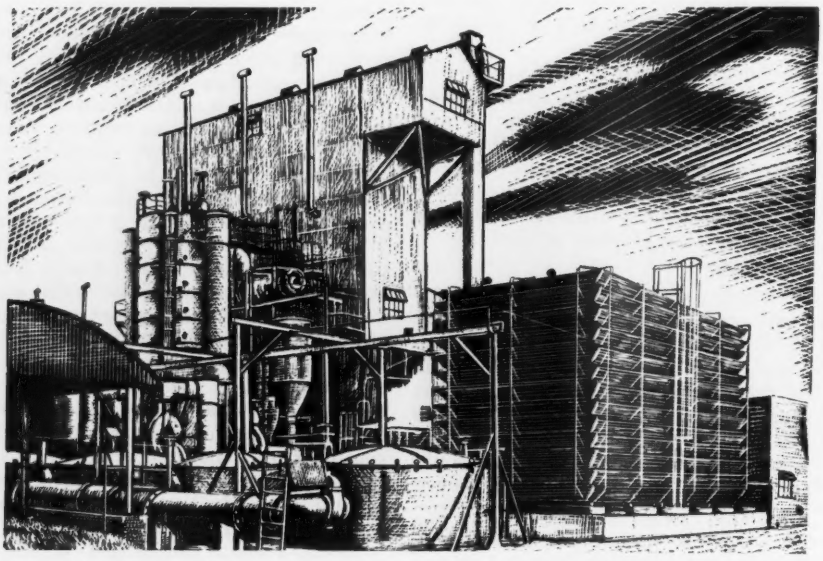

Open-Hearth-Furnace Instrumentation

By E. Rogers, B.Sc.

SYNOPSIS

A consideration of the difficulties of the subject leads to the statement of requirements for different classes of furnace operation. The variables of the open-hearth process are studied with the aid of a diagram showing inter-relationship. It is then decided which variables should be measured under the classes previously stated. Consideration of methods of measurement and presentation gives a plan for instrumentation of open-hearth furnaces in general.

Introduction

APPLICATION OF INSTRUMENTS IN MELTING SHOPS

THIS paper presents an outline of the principles which govern the application of instruments to open-hearth furnaces, and specifies the minimum number of instruments which is required before an installation can be regarded as satisfactory, and complete, for maximum production. The fact remains, however, that no furnace in this country yet possesses this desirable minimum ; a few shops have almost the complete list, and the vast majority have only one or two.

Another remarkable feature is that whilst nearly all shops have a few instruments there is no unanimity as to what these instruments should be ; one shop may be completely equipped with checker-temperature recorders and little else, another may manage very well with only the recording of flue draughts to assist the melters' judgment.

The manager about to undertake the extensive provision of instruments will at once ask the reason for this. Is it due to the fact that the instruments commercially available areun satisfactory ? Are melting-shop managers and melters too conservative in outlook ? Or are instruments not necessary for efficient steelmaking ? It is also probable that he will want to add his instruments one or two at a time, and will want guidance as to which should be installed first. The view that instruments are not necessary for efficient steelmaking can be dismissed at once. The proof of this is the good results which are being obtained, today, from one or two works with melting-shop plant which is very old and poorly laid out, yet which is well equipped with instruments.

The other factors are sufficiently important, however, to merit consideration in detail.

The first point to be considered is whether existing instruments are satisfactory. Now it is shown, in the earlier part of this paper, that because of the extremely difficult conditions both of " crude " surroundings and high temperature, most present-day open-hearth instruments are subject to appreciable errors of one kind or another, when measured by ordinary scientific standards. The knowledge of this may have created a prejudice in some managers' minds. The reply to this is that the manager is interested in production and not in scientific accuracy. For instance, he is not fundamentally interested in gas flow as cu.ft./hr., he wants to know whether his gas flow is rising or falling, or is the same today as it was yesterday ; and for this purpose an arbitrary scale is quite sufficient. If the meter readings are low, provided the error is stable and consistent, no harm is done.

It has been shown, already, that the total-radiation pyrometer is subject to some inherent errors which are quite serious from the scientist's point of view, yet no manager should be deterred from using one for this reason, so long as the nature of these errors, and the precautions to be taken, are well understood. He wants to know when the temperature at which the roof is endangered is approached, and a red line on an otherwise blank scale is all that is required. As far as production goes, it does not matter to him what figure is ascribed to the " red mark " point provided this remains constant. The scientist may disagree with this view, but it is a fact that the use of these admittedly imperfect total-radiation pyrometers has enabled some shops to attain outputs considerably in excess of those that they would reach without them.

Another matter causing doubt on the suitability of instruments, is the often-stressed necessity for adequate maintenance and the knowledge that in some shops instruments are lying unused owing to breakdown and the absence of trained maintenance staff. This is largely the fault of the pre-war salesman who exaggerated the ability of instruments to work without attention ; fortunately, the fact that manufacturers can now sell all the instruments they can make, has reduced this particular form of activity. Another hard fact is that no instrument, by itself, can show a great improvement in furnace efficiency without very persevering and intelligent use ; yet the natural instinct of the shop manager is to tread warily and to install instruments one at a time. An instrument is part of a team and cannot function at its best when alone. Consequently we find too many cases where an instrument has been put in with no appreciable effect on the furnace.

The second point is the outlook of the manager and melter. The manager may be reluctant to add equipment which may possibly be an additional source of

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mechanical trouble, and which in itself cannot guarantee additional output. The answer to this is that almost all advances in melting-shop equipment involve more sources of trouble and the need for additional staff. For instance, charging machines often break down and require considerable maintenance, yet there is no suggestion that a return to hand charging should be made. The melter may dislike instruments because they are often able to reveal bad practice on his part, but perhaps it is fairer to say he dislikes them because he feels that his job involves skill which has been laboriously gained over many years, and instruments may eventually enable some "upstart" to do the same job with much less experience. The answer to this is that the extensive use of instruments, far from enabling a melter to be less skilled, demands, more than ever, the best he can give in the way of intelligent use of the readings, and appropriate action.

The following guidance on the previous points may be given :

1. No manager should be asked to accept an instrument until he is satisfied that he will be able to maintain the instrument in good working order, that he clearly understands what the instrument can do and what it cannot do, and unless he is willing to give it an extended trial, remembering that there will probably be some months of teething troubles, and still more months of trial and error before the melters have learned how to use it.

2. No manager should install an instrument without an attempt to explain its purpose to the men. He may, in some cases, have to insist on its use in the face of initial opposition, but this opposition is likely to be much more prolonged in the absence of the proper approach in the first place. Until the manager himself has become familiar with the instrument, and the men have become thoroughly used to its presence, it is almost certainly unwise to insist on any rules to be observed in relation to the readings.

The manager should, of course, be discreet in telling the men of possible errors in the instrument, as some melters are not able to appreciate the difference between errors which matter and those, which from the production point of view, are immaterial.

Coming to the question of which instruments (in the absence of the complete installation recommended later) should receive priority in installation, it is extremely difficult to give a ruling which will apply to all melting shops ; for even the members of the Open-Hearth Instruments Sub-Committee are by no means unanimous on this point. It must be re-emphasized here that any instrument loses a great deal of its value if installed alone. At the same time it is recognised that it is expecting rather much of a manager, whose shop may have practically no instruments, suddenly to install the complete set recommended. Opinions vary as to whether it is desirable to install instruments one by one, and so get the melters used to them gradually (at the expense of not getting the full benefit from the instrument), or whether a complete installation should be put in at once.

The question of which instrument is the most important must depend, largely, on individual shop conditions and this is why there is no unanimity in the industry on this point.

Some shops (particularly those with acid furnaces making medium and high-carbon steels) seldom experience roof trouble, and a roof may last several furnace campaigns. These furnaces often have small valves and inadequate producers. Here the installation of, say, roof pyrometry should take second place to gas metering and pressure recording to ensure that the fuel input is maintained at a maximum, as there is obviously little risk of damaging the roof and the available heat input is probably insufficient to enable any rule of maintenance of maximum roof temperature to be applied. On the other hand furnaces making large tonnages of mild and low-carbon steels are driven hard, and their roofs suffer severely. Provided fuel supplies are adequate the critical quantity here is roof temperature and this is likely to be the most important measurement.

In other shops the furnaces (particularly those fitted with waste-heat boilers and powerful fans, those handling bulky scrap which damages the doors and jambs, or hot metal furnaces in which "foaming" is troublesome) may benefit most from recording and automatic control of roof pressure ; in this connection it is noteworthy that most American shops regard this measurement as one of the most important.

To sum up, a manager wishing to install only one or two instruments (remembering that this procedure is to be deprecated) should seek advice in the light of conditions applying in his shop. Mr. F. L. Robertson, from long experience with numerous instruments on furnaces making medium-carbon and low-carbon steels on a high production basis, considers that roof-temperature measurement, in conjunction with gas flow, will in itself lead to substantial improvements in production, and the performance of plants in which these instruments are installed strongly supports this view.

CORRECT USE OF INSTRUMENTS

Emphasis is placed on the freedom of action which must remain with the melting shop manager. In our present state of knowledge a universally applicable set of rules cannot be provided ; we are a long way from the stage when it can be stated that "all 80-ton fixed basic furnaces should maintain the gas flow at x cu. ft /hr. for y hours, etc. . . ."

For the guidance of a manager not accustomed to extensive instrumentation, and who is about to apply one or more new instruments for the first time, the following course of action is suggested. For the first one or two campaigns after the installation is complete, little or no definite instructions should be given to the melters, but the shop should be run very much as before, the management and men feeling their way with the new equipment. During this period any "teething troubles" will show themselves and their cure may be found. Also, during this period the recordings should be carefully studied, for the information they give on normal furnace operation.

After such an initial period (which may be as much as 8 to 12 months), the manager will have accumulated

enough information to enable him to devise certain rules. He should know within what range of gas and air flows, roof pressures, and so on the furnace works best, and he can prepare a simple set of rules to give the melters for the regular working of the furnace. It may be necessary to change such rules in the light of further experience, but one shop recently showed a surprising increase in output by selecting certain rules of working (not necessarily the optima) and disciplining the shop to run the furnaces regularly to the instructions and instrument readings given. An American view is that a new instrument should be installed on all furnaces in one shop at the same time. This has proved to be an advantage in that the melters can get together and discuss the instrument.

This does not mean that no improvement at all may be expected for the first few months after an instrument is installed. The very presence of an instrument on the melting stage will have a desirable psychological effect on the men, but it is likely that the early benefits will be more of this nature, and the real and fundamental gains due to the instrument will not appear until later.

The report which follows is a wide survey of the problem of open-hearth furnace instrumentation, which is obviously the first task of a committee studying this matter. Detailed study of particular instruments and their application follows at a later stage ; in the meantime it is clear that anyone contemplating installation of an instrument should, in addition to consulting the Sub-Committee, the staff of the British Iron and Steel Research Association, and the instrument makers, visit other plants which already possess these instruments. All the instruments recommended here have had trials in at least one melting shop so that practical experience is available.

AUTOMATIC CONTROL

This paper restricts itself to the study of instruments required for the indicating or recording of conditions within the furnace system. It is not concerned with the question of which automatic controls are desirable or available, and leaves it open whether the information or signal provided by the instrument is acted upon manually or mechanically.

It is only recently, and largely as a result of intensive study during war-time, that the subject of automatic control, and the application of servo mechanisms to transmit the signal received from an instrument to the actual controlling mechanism (*e.g.* valve or damper) have been brought to the attention of the industry.

The application of automatic control might, at first sight, seem simple in view of the existence for many years of automatic control in other industries, but the subject is actually extremely complex. Little progress can be made in this direction until the mechanism of operating valves and dampers is greatly improved from the crude system of chains and pulleys still in operation in many works. The problem of automatic control of furnaces may be divided into three stages :

(*a*) The provision of instruments to give the signal (*i.e.*, to measure the deviation from the desired control point).

(*b*) The provision of a satisfactory mechanism for transmitting a correcting influence to the valve, damper, etc. Whether or not the correction is applied by human agency or automatic controller, a good mechanism for this purpose is essential to the best operation.

(*c*) The installation of an automatic control link to replace the human element in assessing the amount of correcting influence to be applied to the transmitting mechanism in consideration of the deviation.

This paper is concerned with the first of these stages ; the second and third are being actively studied by the Plant Engineering Division of the British Iron and Steel Research Association.

Generally speaking, the application of instruments can be quite satisfactory without the final stage of automatic control, provided the melters are alert, but a few items (*e.g.*, furnace roof pressure) involve such frequent and varied oscillation that manual control cannot be completely satisfactory, and automatic control is essential. It is difficult to compile a list of the variables requiring automatic control, and as with instruments there is little agreement in the industry on the relative orders of importance of various controls. However, a controlled furnace would not be complete without control of the following :

(i) Gas main pressure
(ii) Furnace pressure
(iii) Roof temperature
(iv) Air to gas ratio
(v) Reversal.

The objects of this paper are :

(*a*) To review briefly recent work on the fundamentals of the process in order to decide which variables should be measured, under three classes, as follows :

Class P (Primary)	Instruments which will allow the operator to control the process in accordance with the manager's instructions.
Class S (Secondary)	Instruments which are not of first importance in the control of the steel-melting process, but which are very useful to the melter and manager for routine fault-finding and checking of plant.
Class R (Research)	Instruments which will allow the manager to obtain data for the most efficient operation of his plant.

(Instruments for Class R will not necessarily be provided on all the furnaces in one shop.)

(*b*) To evolve a plan for the presentation of the measurements.

(*c*) To discuss the methods of measurement.

(*d*) To promote discussion among steelmakers.

APPLICATION OF INSTRUMENTS TO THE CONTROL OF MELTING FURNACES

THE VARIABLES AND THEIR GENERAL INTERCONNECTION

The goal of open-hearth furnace operation is the highest rate of production of steel of proper quality consistent with good refractory life and fuel economy. Whether maximum output should be attained at the expense of refractory life and fuel consumption or *vice versa*, depends on local economic conditions and

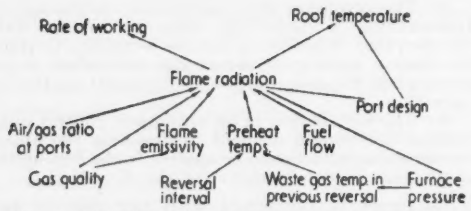

Fig. 1—Relationships between major variables

is outside the scope of this paper, although a complete instrument installation will be of the greatest assistance to a manager in the assessment of these economic factors. It is evident that instrumentation itself has the following three objectives :

(*a*) To enable the operator to control the variables so that the heat flow to the charge is a maximum consistent with satisfactory refractory life.
(*b*) To give the operator an insurance against excessive damage to refractories.
(*c*) To save fuel.

The interrelation of the many variables governing the process are more easily studied with the aid of a " family tree " (*see* Fig. 1) which has been drawn up from the study of two recent reports of experimental work on the open-hearth process.[1, 2] This is an attempt to present in concise form the interrelation of the major variables affecting furnace performance. It should be possible to control the process as far as flame radiation and roof temperature, and it is worth while noting that control of fuel input, alone, does not give complete control over flame radiation or roof temperature.

The master variables are discussed under the following headings :

Furnace pressure
Preheats and frequency of reversal
Fuel flow
Air/fuel ratio
Gas quality
Emissivity of flame
Limits imposed by refractories
Steel temperature

Furnace Pressure—It has been established both practically[3] and theoretically[10] that to prevent ingress of cold air to the furnace chamber, the pressure under the roof should be maintained at a high positive value so that the atmospheric pressure line inside the chamber is near sill level. Where a high roof pressure is used, port design, air-gas mixing, and port maintenance become increasingly important in order to obtain a compact flame well down on the bath, and to prevent excessive " sting " at the doors. In practice the furnace pressure cannot always be as high as the theoretical optimum because of excessive flame sting through the doors.

The measurement of furnace pressure comes, therefore, in class P (a primary control instrument).

Preheats—The main factors affecting preheats are the checker and uptake temperatures, which in turn depend on waste-gas temperatures, reversal frequency and the amount of the air infiltration through the doors, the latter being again governed by furnace pressure.

Theoretically it should be possible to attain higher preheat temperatures with shorter intervals between reversals, with the maximum at zero time interval. However, the time taken to operate the reversing mechanisms and re-establish gas flow is appreciable compared with normal time intervals (*see* Fig. 2). Although the values given in Fig. 2 are for large American furnaces, it is reasonable to infer that there is an optimum-time interval for any particular set of operating conditions on a furnace and that this interval is likely to be considerably shorter than present practice in many plants. The fact that the loss of preheat is not large for wide variations in time interval, partly justifies the present system of reversing on a set time interval.

There is little justification for reversal carried out on the temperature difference between ingoing and outgoing checkers, because the signal is a comparison between two different quantities, and even dependent on different reversals. This is particularly applicable when the air-checker " temperatures " are measured by total radiation pyrometers sighted directly on to the checker brickwork. The waste gases with high CO_2 and H_2O contents would seriously affect the signal in the near infra-red range, where the total radiation unit is most sensitive. At the ingoing end, the signal would be a fair indication of the surface temperature of the brickwork, but at the outgoing end the signal would be influenced by the waste-gas temperature, owing to the high CO_2 and H_2O content of the waste gases.

While ensuring maximum regenerator efficiency, the operator must be able to detect asymmetric preheat between opposite ends, and prevent overheating of the refractories in the regenerator system. It has been shown[1] (*loc. cit.*, pp. 55 and 58) that a large proportion of the preheat is obtained from the flues joining the top of the checkers to the ports, and considerably higher temperatures exist in these flues than in the checkers. In order to assess asymmetry and guard against refractory damage, measurements of brick surface temperature should be taken in the air uptakes at each end. This position is more logical than the more customary position at the top of the checkers, but it has been found difficult, in at least one installation, to maintain pyrometers in the uptakes due to the flame being present during the waste-

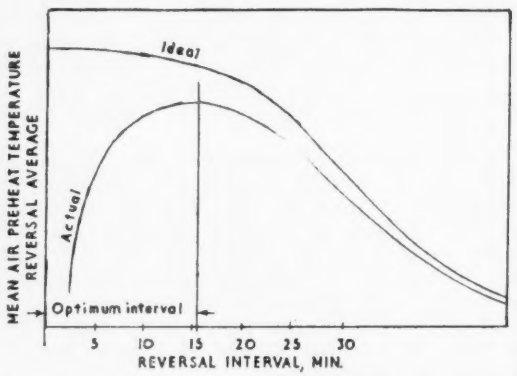

Fig. 2—Schematic curves of relationship between reversal interval and efficiency of heat interchange by regeneration (Larsen and Shenk[1])

gas period, and most works prefer the measuring point to be at the top of the checkers. However, flame in the downtakes would seem to indicate poor combustion conditions.

The curve giving the optimum value for reversal interval can only be determined by a large number of actual-reversal-interval/average-true-air-preheat-temperature measurements (*e.g.*, as determined by suction pyrometer). Having determined this curve, reversal should then be carried out at the optimum-time interval, modified, when necessary, with regard to air-uptake temperature, to prevent refractory damage and to correct for asymmetry.

Many furnaces record checker-temperatures in all four checker chambers. If the object of recording checker or uptake-temperatures is to avoid (*a*) asymmetry of temperature conditions and (*b*) danger to the refractories, it should be sufficient to record temperatures in the air system only. Most operators of gas-fired furnaces, particularly those using mixed gas, prefer however to have a knowledge of the temperature in the gas regenerative system as well as in the air, but such a measurement cannot be regarded as essential. Even in mixed-gas furnaces it is becoming recognised that the required flame luminosity is better obtained by additions of tar or oil rather than by artificially high preheat temperatures.

To sum up, the measurements under the heading of preheats are, therefore, Class P—air uptake temperatures, and Class R—true air preheat temperatures (*e.g.*, by suction pyrometer).

Fuel flow—The actual fuel input to a furnace can affect both the total heat flow to the charge and the temperature distribution over the furnace length.

It is not widely appreciated that too much fuel can be supplied to a furnace, so that a considerable amount of unburnt gas passes to the downtake, thus removing heat from the furnace chamber in the same way as excess air. This point may be particularly important where poor combustion conditions are encountered and more gas is supplied in an attempt to increase the heat flow to charge. An example of a furnace working under such conditions was discussed in a paper published some years ago.[11]

It must be the objective of the operator to supply the maximum fuel which can be burnt efficiently while preventing damage to the furnace refractories, particularly the roof refractories.

In gas-fired furnaces asymmetry is often caused by differences in port wear and pressure drop in the flues at opposite ends of the furnace. Present practice often allows the gas flow to be different at opposite ends and the resulting asymmetry is either ignored, or corrected by varying the reversal intervals.

This shows up an obvious fault in the system of reversal based on checker-temperature differences, in that asymmetry is then always attributed to asymmetric preheats. The subsequent correction of asymmetry by altering the reversal intervals makes it necessary to carry different gas rates on each end and vitiates the first objective of open-hearth operation, namely, to burn the maximum gas consistent with refractory safety.

The facility for ordering the fuel supply to be maintained as far as possible at a set value is probably one of the most important of the manager's reasons for providing metering instruments.

Fuel flow is therefore a class P measurement.

Air/fuel ratio—Present practice in most cases neglects air/fuel ratio control but it has been established[3] (*loc. cit.*, p. 406, Section (*b*)) that there is an optimum value for a particular furnace, and departure from this value reduces the effective heat flow to the bath. In many shops the air rate at the intake is maintained approximately constant irrespective of changes in the fuel rate. This may be due in some cases to the air-regulating valve being in an inaccessible place, and, in the absence of instruments, to the difficulty of observing any effect of adjustments. Another reason is that the air rate is often set to the correct ratio for full fuel flow, so that excess air is available when the fuel flow is reduced because of roof overheating. The excess air may then prove a useful roof-cooling factor. However, the use of a fixed air rate for this purpose encourages poor fuel regulation because the melter can safely alternate between too much fuel, and too little, when the object should be, at all times, to maintain the maximum fuel consistent with roof safety. In an ideal furnace the theoretical air/fuel ratio (given by the quantity of air just necessary fully to burn a given quantity of fuel) is the optimum value. However, in practice the optimum ratio usually indicates that excess air is necessary. A small excess of air is necessary for bath reactions, and F. L. Robertson (*see* p. 72) has calculated that as much as 15% of the air theoretically necessary for combustion may be taken into combination with the charge during melting down, thus increasing the air requirements by this amount. In addition, there is evidence that the use of excess air permits of harder driving of the furnace without damage to the roof, but where a large excess of air is required to burn the fuel, port design and combustion conditions may be suspected.

The operator can only maintain a set air/fuel ratio at the valves. It must be decided how far this can be used to control the actual ratio at the ports.

The most serious interfering factor in gas-fired furnaces is gas leakage and air infiltration in the system between valves and ports. Combustion control can only be satisfactory if three independent variables (gas flow, air/gas ratio, and air infiltration) are controlled. As the air infiltration cannot be eliminated it must be held within limits, and a measure of air infiltration is of primary importance. Maintenance of checkers and uptakes will have to be more effective than is customary at present. In order to control combustion conditions it is necessary, then, to limit the amount of infiltration and at the same time obtain a signal which can be used to hold the air/fuel ratio at the valves near an optimum value.

Several works have built an orifice in the stack flue so that the waste gas can be metered and compared with the theoretical flow obtained from air and fuel inputs. In one case at least, the extent of the air inleakage has been shown to be very serious, probably due to lack of furnace pressure control. It is suggested that a waste-gas metering device should be a class S instrument which can be used to indicate the amount of air infiltration, and hence the condition of the

checkers and uptakes, provided that the intelligent use of roof-pressure control limits direct infiltration at the furnace doors.

Where all the fuel is burnt in the furnace chamber and theoretical air is supplied at the ports, the carbon dioxide content of the waste gases should remain at a constant and calculable value, but these ideal conditions are practically never realized. Carbon dioxide given off by the bath may interfere, particularly if limestone is used in the furnace, and the measurement is also affected by the dilution of the waste gases due to air infiltration. In order to minimize the dilution effect the sampling point must be in the downtakes, but recent tests have shown that in some furnaces the separate downtakes carry waste gases of very different composition, and it is by no means easy to obtain a representative sample. Provided that this difficulty can be overcome, that air inleakage is not serious, and that heavy CO_2 emission from the bath is not taking place, the CO_2 content of the waste gases may be used under class R to find the optimum air/gas ratio at the valves.

It is possible that the other waste gas analyses such as oxygen and carbon monoxide may be preferable as alternatives to, or in addition to carbon dioxide analysis. However, the error of dilution due to air infiltration would occur on any waste-gas analysis. CO and O_2 recorders have been developed as experimental instruments but do not appear to have yet reached the stage of general routine application.

Measurements of air infiltration on production furnaces are at present being carried out by the Steelmaking Division of the British Iron and Steel Research Association. At least one firm has made fairly complete waste-gas analysis part of the routine measurements on a production furnace. The results of these investigations should throw light on infiltration and combustion control problems.

As an alternative to the measurement of CO_2 in waste gases it has been suggested that the optimum air/gas ratio may be found by using a direct measurement of flame radiation as the controlling indication. On a fully instrumented furnace it may be possible to reduce the masking effects of other variables, and trials with this in view are now being carried out by the Physics Department of the British Iron and Steel Research Association.

Some operators use a " CO_2 in waste gas " indication as a class P (routine control) instrument in an endeavour to maintain the optimum air/gas ratio at the ports. Nevertheless, it is considered here that the method of operation most likely to give close control over combustion conditions is the maintenance of a preset air/gas ratio at the valves as indicated on the flow meters, provided air infiltration to the working chamber and the rest of the system is fairly strictly controlled by observation of furnace pressure and waste-gas flow respectively ; this preset ratio could be adjusted to give the optimum ratio at the ports by means of a class R instrument. It should be noted how furnace pressure affects many of the other variables and this may explain the stress laid on this measurement in American literature.

Measurements involving air/fuel ratio are then :

Class P—Air flow and gas or oil flow near valve
Class S—Waste-gas flow
Class R—CO_2 in waste gases (downtakes)
Flame radiation

Gas Quality—In a producer-gas-fired furnace the gas quality is usually an unknown variable, although it is probably one of the most important factors governing combustion and flame characteristics. Changes in gas quality directly affect the flame emissivity and to some extent the optimum air/gas ratio required. In producer-gas practice it has been observed that the melters sometimes complain of a shortage of gas although the meter shows a substantial increase in flow. This is due to bad channelling in the producer allowing an increased flow of very indifferent gas for a short period.

The operator should have some indication of the quality of the gas he is using in order to correct the conditions at the producer, and to interpret correctly the readings of his gas-flow meter. Calorific value and gas temperature will give indications of producer conditions, while gas-main pressure will show the reserve or deficiency due to variations in demand where a common main supplies more than one furnace. An additional reason for measuring gas temperature at the valve is that a high temperature must be maintained at this point to minimize metering difficulties due to deposition of tar on the orifice or venturi.

Class P measurements under the heading *Gas Quality* are then :

Calorific value
Gas temperature at valve
Gas main pressure.

In addition there must be adequate instrumentation and control of the producer itself (*see* p. 71).

Emissivity—The flame emissivity varies with producer operating conditions and may vary with gas preheat if the gas preheat is insufficient to start " carbon skeleton formation." However, this subject has been frequently discussed[1] (*loc. cit.*, p. 29) and no further mention will be made at this stage.

In a slow-working furnace a measurement of flame emissivity may give a clue to the reasons for the low heating power of the flame, and the most suitable producer conditions or type of coal determined by experiment.

The measurement of flame emissivity is, therefore, class R.

Limits imposed by refractories—Refractory damage by overheating may occur in the furnace roof and walls or in the checkers and uptakes. There is no indication that dangerous temperatures are necessarily reached in both roof and checkers at the same time.

(*i*) The actual limiting temperature at which the roof refractories " run " cannot be determined with any great accuracy owing to the varying nature of chemical attack (fluxing) under operating conditions. It is imperative that the roof temperature be allowed to rise to the absolute limit consistent with safety in order to obtain maximum heat transfer to the bath by radiation. The limiting temperature will depend to some extent on the furnace design and local practice, so that for a particular furnace, it must be found by observation.

The whole of the furnace roof will not be at the same temperature, therefore the limiting measurement must be made at the hottest point. Apart from local overheating due to cold scrap deflecting the flame, most furnaces are fairly consistent with regard to hot spots. Roof wear diagrams[1] (*loc. cit.*, p. 81) should give sufficient information to enable the most suitable point for measurement to be chosen, though several firms now prefer to measure roof temperature in two or even three positions. If a furnace has been operated without roof-temperature control, and no danger has arisen, it may be an indication that the furnace has not been driven sufficiently hard, or that combustion and preheat efficiencies are not all that they might be.

(*ii*) The highest temperatures in the checkers and uptakes are usually encountered between the checkers and ports. Although the temperatures may not be as high as in the outgoing part of the melting chamber, there is still risk of refractory damage as slag attack is sometimes heavy, velocities are higher, and in any case some operators use slightly lower grades of refractory in this position. The measurements to be used for preheat control should also serve as limit indications to prevent refractory damage. Such limit indications would provide an overriding control of reversal period.[4] As the gas preheats are much lower than the air preheats for normal port designs, it will only be necessary to determine temperatures in the air uptakes.

At present dangerous temperatures in the uptakes are not so common as dangerous roof temperatures (although much depends on the refractories used for the uptakes), but more efficient combustion and preheat control may call for more careful measurement of checker and uptake temperatures.

Class P measurements concerned with the limits imposed by refractories are, then :

Roof temperature
Uptake temperatures

Liquid steel temperature—This affects production considerably as many cases have been encountered where time has been lost owing to unnecessary waiting for "heat," and others where yield has been lost owing to tapping too cold with resultant skulls. For many steels too, there is an optimum-temperature range for tapping and teeming. Many works now find that the use of some more precise method of temperature measurement than the rod or the visual appearance of the steel is desirable.

Some works are now controlling bath reaction to a definite schedule based on the carbon-temperature relation. This is a case where instrumentation allows a melting technique to be used which was previously unattainable.

Liquid steel temperature should therefore be a routine measurement, *i.e.*, class P.

APPLICATION OF CLASS S INSTRUMENTS TO FAULT FINDING

Frequently troubles arise during open-hearth furnace operation which, although capable of solution by the use of the control instruments recommended above, would demand for such solution rather laborious interpretation of the records. To avoid this, certain instruments which afford an immediate guide to such troubles are recommended, although when the furnace is operating satisfactorily, their readings are not used for control purposes once the "normal" readings have been established by experience.

Class S instruments to be recommended are :

Gas-uptake pressure recorders
Stack-draught recorder
Temperature recorders for the base of the air checkers
Waste-gas flow indicator

Gas-uptake pressure recorders[22] are used as a guide to port conditions. Normally, a certain gas flow as indicated on the flow meter will demand a certain pressure in the uptake. Variations in this pressure for the given flow indicate making-up or opening-out of the gas port.

Normally the stack damper is to be operated according to the readings of the roof pressure instrument. Choking up of the furnace system is indicated by abnormally high stack draughts in relation to a given roof pressure. Hence a stack-draught recorder can be very valuable, although it should not be used as a main instrument of control.

Waste-gas temperature readings below the checkers may indicate abnormal furnace conditions such as failure of the checker system.

Waste-gas flow measurement is examined on p. 61.

PRESENTATION

The measured quantities which, for convenience, are summarized in Table I should be presented in a manner which ensures that the most useful information is given in the form in which it can be used for furnace control. Furthermore, the psychological effect of the presentation is very important. The following is the recommended routine for furnace measurements :

Class P

(*a*) Gas flow indicated and recorded in cu. ft./hr. (or oil in gal./hr.).

(*b*) Air flow indicated and recorded in cu. ft./hr. and directly as air/gas ratio.

(*c*) Furnace pressure indicated and recorded as differential with atmospheric pressure.

(*d*) Roof temperature indicated and recorded on

Table I

SUMMARY OF QUANTITIES TO BE MEASURED

Class P (primary or routine control)	(*a*) Gas or oil flow at valve (also atomizing medium in oil-fired furnaces)
	(*b*) Air flow at valve
	(*c*) Furnace pressure
	(*d*) Roof temperature (maximum)
	(*e*) Air-uptake temperatures
	(*f*) Calorific value of gas
	(*g*) Gas temperature at valve
	(*h*) Gas-main pressure
	(*i*) Liquid steel temperature
	(*j*) Reversal time.
Class R (special instruments for research)	(*k*) True air preheat temperatures
	(*l*) CO_2 in waste gases
	(*m*) Flame radiation
	(*n*) Flame emissivity.
Class S (secondary or fault-finding)	(*o*) Pressure in gas uptakes
	(*p*) Stack draught
	(*q*) Temperature at base of air checkers
	(*r*) Waste-gas flow.

temperature scale with adjustable danger mark and an alarm signal which operates when temperature exceeds the danger point at any one place of measurement.

(*e*) Air-uptake temperature at both ends recorded on the same chart. The "butterfly" pattern produced indicates asymmetry and maximum temperatures at a glance.[5] Two readings should be obtained from both pit and stage side uptakes. An alarm signal should be fitted to give warning of dangerous maximum temperatures.

(*f*) and (*g*) Gas temperature at valve and calorific value recorded on adjacent charts; if possible on the same chart. These two variables are intimately connected with conditions at the producer and it is important that relative as well as absolute values are presented. Where a gas main is supplied by several batteries of producers, calorific value and gas temperature should be recorded at each battery in addition to the melter's instruments.

(*h*) Gas-main pressure indicated and recorded. In practice some shops have not sufficient reserve of gas to supply all furnaces on maximum demand so that the melter should have an indication of the gas pressure available at any instant.

(*i*) Liquid-steel temperature indicator and recorder. It should be possible to arrange the installation to serve several furnaces.

(*j*) Reversal indicator which gives warning light after set-time interval lapses, and indicates the limits between which the furnace can be reversed to correct for asymmetry while maintaining a high regenerator efficiency.

Class R

(*k–n*) These instruments will not normally appear on each furnace panel and portable units will be preferable.

Class S

(*o*) Pressure in gas uptakes. Both ends recorded on the same chart.

(*p*) Stack draught. Recorded.

(*q*) Temperature at base of air checkers. Both ends recorded on same chart.

(*r*) Waste-gas flow indicated and recorded in cu.ft./hr.

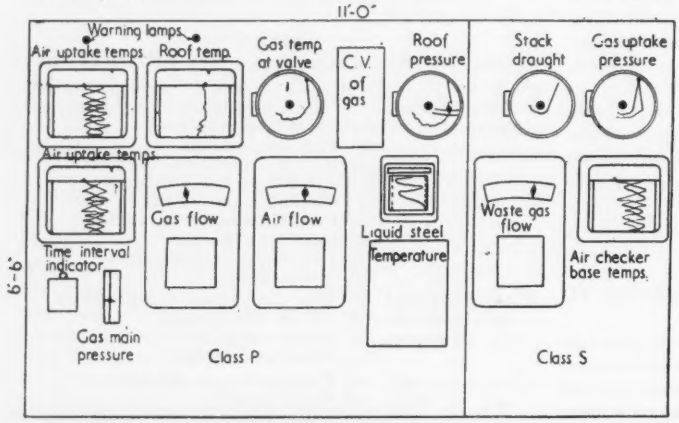

Fig. 3—Panel layout

Panel layout is restricted by the small space available in most melting shops and it is often necessary to use several small panels which will fit into existing spaces rather than one large panel. Wherever possible, it is recommended that one central panel be used, otherwise there is the possibility of an inaccessible instrument being ignored. A suggested layout is shown in Fig. 3, though of course there are numerous alternatives. The instruments are arranged so that related variables are indicated near to each other. Class P instruments are the basic control indications for routine operation. The class S instruments are quite distinct in that they will only be referred to infrequently so they are grouped together and apart from class P instruments. It is likely that in the future all furnace controls will be servo-operated from a central point and this must be borne in mind when laying out the instrument panel.

At present most instrument firms have a long waiting list for new instruments. Some makers provide their own standard panels and acceptance of these panels may hasten delivery. In order to help the instrument industry to adjust its programme to deal with future demands, the British Iron and Steel Research Association is carrying out a survey of the number of instruments required in the steel industry to bring instrumentation up to a suitable general level, and the number of years over which this change should take place.

At present few works appreciate the fact that instruments must be maintained by trained personnel. The responsibility for the accuracy of the instruments should lie solely with the maintenance crew. Melters should be merely told that an instrument is "in order" or "unserviceable." Discussion between maintenance men and melters on the source and magnitude of errors may create unreasonable fears in the mind of the melter. The employment of juniors in the capacity of maintenance staff is to be discouraged, except as assistants to an adequate body of qualified men.

THE MEASUREMENTS FOR ROUTINE CONTROL (CLASS P)

GAS FLOW

Methods of measuring gas flow are given in any textbook of hydraulics, but the only method which need be considered is the use of a constriction, such as a circular orifice or a venturi, to produce a pressure-differential corresponding to the flow. The use of a Pitot tube is not practicable for continuous recording as the flow of gas to a furnace is hardly ever steady enough in any one place to enable a Pitot tube to be permanently positioned for recording purposes.

Furnaces using clean gas such as coke-oven gas, and/or blast-furnace gas, present no problem as such gas is almost invariably supplied to the furnace through pipes in which there is a sufficiently straight length for the insertion of an orifice plate or venturi in the normal way. The gas being

relatively clean and cold, maintenance of the orifice presents no difficulty, although precautions against chemical attack may be necessary if the gas contains much sulphur or moisture.

However, many furnaces in this country still use hot raw producer gas, and this fuel is likely to be used for many years to come.

The accurate metering of hot raw producer gas presents a special problem for two main reasons.

(*a*) The available pressure in the main is usually little above that required to supply the quantity of gas necessary to operate the furnace. Total pressure loss across the metering device, therefore, must be a minimum, while ensuring sufficient differential pressure drop to operate a meter.

(*b*) Deposits of tar and dust form relatively quickly both in the main (particularly where the velocity is suddenly reduced or eddies formed), and on the surface of the orifice or venturi. The metering device must therefore be easily maintained in a clean condition and designed so that any deposits cause a minimum error in the measurement.

There are several methods of producing a pressure drop in a main carrying hot raw producer gas :

Steel-Plate Orifice
Snub-nosed Brick Orifice
Refractory Concrete Venturi
Use of a Constriction

In the case of the first three methods mentioned it is necessary to fit suitably placed pipes so that steam or compressed air may be blown at intervals on to the operating edge of the orifice or venturi in order to keep it clean. In order to avoid the risk of explosion, this should not be done automatically unless an automatic safeguard is provided to cut off the air when the gas flow is near zero.

Steel-Plate Orifice[23]—The edge of such an orifice must be kept sharp and clean. Even very small deposits will produce serious errors in measurement and manual scraping of the edge may very soon alter the characteristics of the orifice. Again, the plate must be removed during the week-end burn-out, as the temperature during this period is high enough to cause deformation. In most cases, scouring by steam does not seem to remove the deposit from the sharp edge.

In at least one installation, however, a steel-plate orifice is said to have been satisfactory.[12] This is almost certainly because in this installation the gas was controlled at a high temperature which prevented the deposition of tar. The dry dust deposit formed was easily dispersed by steam scouring.

The general use of the steel-plate orifice is therefore to be discouraged ; the only advantage being initial low cost.

Snub-Nosed Brick Orifice—An orifice made from special snub-nosed firebricks was developed some time ago, and is in use in some works. From the evidence of users it appears that in certain cases this is a very satisfactory method, but in cases where deposits are particularly hard, due to bad coal or low gas temperature at the metering point, the brick orifice is not entirely satisfactory because steam scouring does not completely remove the deposit.

Compressed-air scouring does not seem to have been tried, but it is possible that hard deposits could be removed in this way, provided that the bricks stand up to the treatment. In practice the deposits tend to build up on the larger diameter and curved portion of the orifice, in which case no serious error is introduced until the actual internal diameter is affected.

Although the pressure loss is not so great as with the plate orifice, the loss may in certain cases cause restriction of gas supply but this can be determined by model tests.

Refractory Concrete Venturi—This is the latest method developed and promises to be the most suitable method of producing the pressure differential with a very low permanent pressure loss, and negligible errors due to deposits. It is possible to build the venturi into existing plant during the short period between cleaning and re-gassing at a holiday shutdown. Very complete details of construction, maintenance, and results on a typical installation are given by Dall and Pluck[1] (*loc. cit.*, p. 35). The main points to be noted are :

1. The ease of construction.
2. The very effective cleaning produced by the compressed-air flame scouring. Some works do not have compressed air available, and it may be necessary to use steam scouring which is not so effective but may serve the purpose if dry steam is used.

It should be emphasized that the amount of air blown in for this purpose is too small to cause any risk of explosion except when the furnace is off gas, and the flow of gas is negligible. This risk can be eliminated by turning the blowing nozzles on *seriatim*, and not all at the same time.

It has been found, however, that if the venturi is installed in a horizontal gas main the installation used by Dall and Pluck (which was for a vertical position) cannot be used. The air-blowing pipes will not remain horizontal, and whilst a similar venturi can be used, the air-blowing device needs slight modification so that only short unsupported lengths of pipe are used.

3. The consistency of contour of the venturi after six months in use.
4. Even in a very irregular location, the flow coefficient is not seriously affected by variations in the opening of the valve. Previous experience with round and square-edge orifices in similar locations has not shown such stability of coefficient.
5. The very small restriction of gas supply imposed by the venturi.

Use of a Constriction—In some old installations the layout of the incoming gas mains and flues is so tortuous and restricted that no possible site for an orifice or venturi can be found. In some such installations the gas flow has been successfully recorded by measuring the pressure drop across a reversing valve of the Dyblie or Wailes type,[19] but this cannot give an accurate result over a wide range of gas flows, although careful calibration with a model may enable quite satisfactory readings for normal furnace control to be obtained.

Further consideration of the measurement of crude producer gas is limited to the brick orifice or refractory venturi methods, although many of the remarks are applicable to the other systems also. The differential pressure pipes connecting the meter to the orifice or venturi should be laid so that any moisture will drain to a catch-pot, or back into the gas main. No pipes should be laid exactly horizontal, and all lengths should be straight, with arrangements for probing at the connection.

Safeguard against blockage is often obtained by blowing a small quantity of air continuously through the pipes from meter to venturi so that gas never enters the pressure pipes. If a very small quantity of air is used through bubblers, no cooling of the venturi pressure connections will result and no tar condensation will occur. However, some operators find the admission of air to the pressure pipes in this way unnecessary. In theory a correction to the meter reading must be applied to account for the chimney effect where the pressure tappings are at different heights. The air-bubbler system will ensure that cool air only is present in the pipes, and the chimney correction will be constant. In most cases the correction is so small as to be negligible.

The correct method and location for installation of orifices and venturis is given in B.S.S. 1042, 1943. In practice, with ordinary producer gas distribution systems, it is seldom possible to conform to these standards. Thus a non-standard location nearly always has to be used, and it is necessary to determine the flow coefficient separately for each installation by means of scale-model tests[13] over a suitable range of Reynolds numbers. Such tests are fairly easy to carry out, but are usually done by the meter manufacturer as a necessary part of the work in connection with every installation.

The most suitable instrument for indicating and recording the pressure differential is the ring-balance meter,[14] giving a linear scale and high sensitivity with sufficient ruggedness to withstand open-hearth shop conditions. However, a point that is not always appreciated is that the instrument functions on heavily loaded knife-edges which will deteriorate if subjected to continuous vibrations. Standard anti-vibration mountings can be obtained which will provide excellent insulation from excessive vibrations. The correction for " chimney effect " can be made automatically on a ring balance meter.

By the use of the methods outlined, many works are now successfully metering and recording the flow of crude producer gas. The chief troubles encountered can be summarized as follows :

Blockage of the Mains and Orifice—This may be due to deposits of soot, fly-coke, or ash, in which case the trouble is normally confined to the main, and the reading produced by the orifice or venturi is not seriously interfered with until the deposits are severe. On the other hand, if the gas tends to be cold, liquid tar may condense and this tar is not always removed from the orifice by the steam or air jets, so that the meter reads high.

The cure for this trouble is to endeavour to make the installations in a vertical in preference to a horizontal section of main, and at a point where the gas temperature is at least 500° C. This latter requirement means that the position chosen should be as close to the producers as possible, otherwise the gas producers might need to be run hotter than usual (with risk of deterioration of gas quality) to ensure 500° C. at the orifice.

Blockage of the Pressure Pipes—This need not cause trouble if the pipes are fitted with plugs at each corner and laid out so that all sections can be rodded through.

Variability of Gas Temperature and Quality. It must be remembered that a gas-metering equipment is calibrated for only one set of temperature, pressure, and density conditions, and that departure from these conditions necessitates the application of a correction. Since the pressure conditions are absolute (not simply pressure above atmospheric) the widest variations in pressure encountered in operation do not affect the reading appreciably, and normal variations in barometric pressure can also be ignored unless specially accurate metering is required. On the other hand (particularly with present-day fuel difficulties) producer operation may be sufficiently variable to produce such wide fluctuations in temperature and gas composition (density) as to vitiate the gas-meter readings completely, and it must be noted that crude producer-gas metering can only be a success if the producers are working smoothly and uniformly. This is not a condemnation of producer-gas metering, but an emphasis on the need for improved producer practice in many instances.

AIR/GAS RATIO

The measurement of air/gas ratio can be considered first as a measurement of air flow, then as a combination of air and gas flows to give one signal. It is only necessary to measure the air/gas ratio near the valves. It has already been pointed out that the air infiltration must be held within reasonable limits so that control of the air/gas ratio at the valves gives control over the air/gas ratio at the ports, although theoretical air at the ports will not necessarily require theoretical air at the valves.

Air-flow measurement is very much simpler than gas-flow measurement but it has its own special problem. Unless a positive air fan is used, very little pressure head can be made available without seriously restricting the flow, as in the absence of a fan the furnace relies on the buoyancy of the hot-air column in the checkers and uptakes to overcome the resistance of the passages. The venturi is the only possible solution when natural air is used, and is also strongly recommended for positive air because of the very small permanent loss in pressure head imposed. When possible the venturi should form the air intake from atmosphere.

Detailed designs of venturi intakes have been drawn up by the meter manufacturers. Most existing air-metering installations consist of an orifice forming the air intake to the positive air fan. Although leaky checker brickwork is often thought to cause a serious discrepancy between the metered air and the air reaching the port, this is not likely to be serious (unless the brickwork is in very bad condition) because the pressure differentials (slight suction in the checker

and slight pressure in the top of the uptake) are very small. Far more serious errors are caused by short-circuiting to the stack, due to leaks in the air-reversing valve, particularly if there is a further air-regulating device in the air line nearer the furnace which causes a build-up of pressure on its upstream side. If air metering—and particularly air/gas ratio control—is to be a success, good airtight reversing valves are necessary.

Meters recording and indicating air/gas ratio are standard practice in boiler plants, but apart from a few isolated instances they have not as yet appeared in the open-hearth shop. Investigation of available meters will be carried out by the British Iron and Steel Research Association in the near future, but in the meantime separate recording of gas and air flows (particularly on one chart as recommended by R. C. Baker[18]) should be used pending the institution of direct ratio recording.

Variations in atmospheric air temperature and humidity do not cause serious errors.

FURNACE PRESSURE

As the object of controlling the pressure in the furnace chamber is to maintain the atmospheric pressure line as near sill level as possible, it would be reasonable to measure the actual pressure at sill level inside the furnace. However, experience shows that the maintenance of the pressure point is not practical near the bath level. Splash from the bath, fettling materials, and cold charge all tend to block or damage the pressure tapping, added to which the wear on the furnace lining is very great at this point. The most satisfactory pressure point is the crown of the roof where the maximum signal can be obtained with relatively little maintenance. Even the highest roof pressures are comparable with the errors obtained in flow measurement due to uncontrollable chimney effects, *i.e.*, one pressure pipe being at a different temperature and level to the other. The measurement required is the differential between absolute roof pressure and absolute atmospheric pressure, and a simple pipe connection from roof to meter to atmosphere will be subject to large errors as shown in the Templeborough trials[1] (*loc. cit.*, p. 156). One method of obtaining accurate measurements would be the remote indicating roof pressure pick-up which has been developed by the British Iron and Steel Research Association, and which is now receiving final trials.

If a pipe is employed to transmit the pressure to the instrument, a compensating pipe should be run from the meter alongside the pressure pipe, with the open end near the roof. Some manufacturers prefer to use one pipe only, as they say that the compensating pipe becomes blocked with dust. These manufacturers say that the error is constant and the melters can soon get used to a false indication, but in some of the present installations the error is by no means constant. There is no reason why the compensating pipe should get blocked if it is installed correctly, and buyers should insist on this being done. However, the use of a compensating pipe precludes the use of a non-differential type of pressure-measuring instrument.

ROOF TEMPERATURE

Suggestions have recently been made in America that the actual roof temperature can be ignored if another variable such as flame radiation is controlled. However, the evidence obtained in the Templeborough trials shows practically no correlation between roof temperature and any other variable. The roof temperature depends on so many factors that the only practical method of operating the furnace at high output and safe refractory temperatures is to have a direct measure of roof temperature.

For the majority of furnaces the highest roof temperature appears to be consistently found on the same part of the roof. Abnormal conditions whicl may cause other hot spots are flame deflection and uneven roof surface, due to slip of the bricks, or stalactite formation—both of which should be quite easily noticed by the melter. A false hot spot may appear where the roof is badly worn and the " black bodiness " is increased by the cavity. In any case, all abnormalities could only be covered by a very large number of measuring points, so that it is reasonable to assume that insurance against consistent overheating of the roof or inconsistent gas practice should be quite adequate. Generally this will only require one measuring point, but where roof wear patterns show serious wear in more than one position the number of measuring points should be considered on the merits of the case. At least one works is now using three measuring points. There is some choice in this measurement, and the possible methods are discussed briefly :

(*i*) Any measurement using a thermocouple built into the roof can be dismissed immediately, because the temperature gradient at the inside surface of the brickwork is so great that large positional errors are introduced, especially when the roof is wearing rapidly. Furthermore, the maintenance of a couple at, or near, roof temperature is impracticable.

(*ii*) Total-radiation pyrometers are in use at several works and whilst they appear to give satisfactory practical service they are open to certain theoretical objections. The furnace atmosphere contains appreciable quantities of CO_2 and water vapour which have large absorption bands in the infra-red region. An instrument sensitive to infra-red radiation will then be influenced by the temperature of the gases in the line of sight. Where a lens is used to focus the radiation it is difficult to obtain a sharp image for all wavelengths and for this reason a mirror may seem preferable. However, a glass lens absorbs some of the infra-red radiation in the CO_2 and H_2O bands so that the error due to gas temperature is reduced where a lens rather than a mirror is used for focusing.

The inherent stability of a simple thermocouple is not present in all the commercial radiation pyrometers, the principal errors being due to ambient temperature changes and drift caused by poor design and the choice of unsuitable materials for the thermocouple.

The radiation unit which would be most suitable for the open-hearth roof would then be insensitive to infra-red radiation. An instrument which is

sensitive to infra-red radiation should make use of a lens rather than a mirror for focusing.

(*iii*) A great deal of work has recently been carried out on photo-electric pyrometers. The two most useful types are the vacuum-emission cell and the rectifier or barrier-layer cell.

The vacuum-emission cell has been incorporated in a satisfactory commercial instrument for furnace temperatures up to 1200° C., but instruments for open-hearth roof temperatures cannot be obtained.

Barrier-layer cells[6] have usually been associated with "drift" but it has recently been shown[7, 8] that cells can be chosen for precise measurement. The simplicity and ruggedness of this type of cell is very attractive. In common with other types of photocell, calibration can be carried out directly against a tungsten ribbon filament lamp whereas the total-radiation pyrometer needs a sizeable black body, which is usually unobtainable.

The results of recent works tests show that the Barrier-layer instrument is satisfactory, and this type would appear to be preferable to other existing commercial pyrometers. It is hoped that vacuum-emission pyrometers will eventually be available also. Nevertheless the present radiation type is giving good service in many works, and provided its inherent errors are appreciated, it fulfils its main practical purpose of safeguarding the roof.

In general, the hottest part of the roof is to be found near the area above the taphole, except where the back wall slopes steeply, when the hot spot is often near the front, above the middle door. The point at which the pyrometer is installed should be chosen so that minimum flame interference is found in the line of sight, and there is little probability of blockage by slag or scrap (*see* Fig. 4).

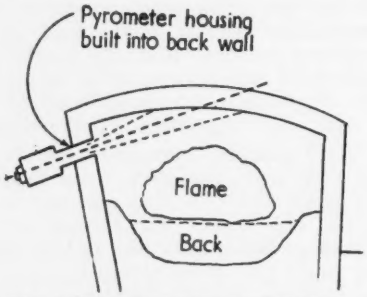

Fig. 4—Roof pyrometer installation

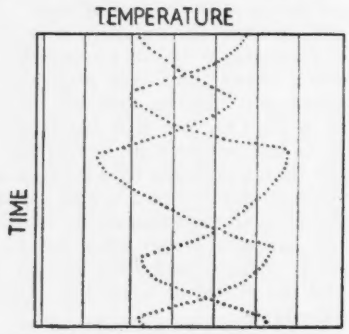

Fig. 5—" Open " pattern of two opposite-end uptake or checker temperatures on same chart

One instrument firm advocates a special brick with a cavity in the outside surface on which a radiation receiver is sighted. However, the temperature gradient at the inside surface of the roof is so great that such a measurement cannot give a signal which can be used to control the roof temperature.

The housing should be designed so that the pyrometer head is maintained at a reasonably constant temperature by water cooling. By blowing air down the sighting, tube blockage is minimized and the tube is protected from serious overheating. It should be possible to remove the pyrometer head easily from its housing so that a disappearing-filament pyrometer can be directed along the line of sight, and so ensure that the angle of observation is the same as that of the radiation tube. The furnace may not be sufficiently "black body" to allow neglect of the difference of angle which may arise if check measurements are taken through the front doors. Theoretically these checks should only be made when the gas is off and the furnace approaches a black body, but in practice the roof temperature drops so rapidly when the gas is off that a determination by disappearing-filament pyrometer, which can be synchronized with the recording instrument it is desired to calibrate, is hardly practicable. Although the errors are relatively small they must be taken into consideration, as accurate roof temperature measurement is essential. It is possible that some of the "errors" of roof pyrometers are in fact check-measurement errors.

The housing should be built into the furnace wall in order to maintain the line of sight. If the housing merely points through an aperture in the wall and the furnace is operated at the correct pressure, smoke may be blown out through the line of sight and this may affect the reading. It is important to provide a robust system of connection to the cable which carries the signal. Ordinary terminals cannot be recommended as dirt and corrosion may set up a thermal e.m.f. at the connections. Suitable connections would be the water-and-dust-proof plugs and sockets developed by the Air Ministry during the war. Cables should only carry asbestos, or other heat-resistant insulation, as the conditions near the furnace break down rubber and polyvinyl insulations.

For recording the signal from total-radiation pyrometers, commercial thermocouple instruments can be used, but for barrier-layer cells a more sensitive instrument is necessary. Two firms manufacture suitable recorders which are now free from teething troubles. As in thermocouple work, a null method (*i.e.*, automatic potentiometer) of measurement is definitely preferable to a direct deflection measurement. If the latter is used, the available instruments record by clamping the free galvanometer indication and marking the position of the needle. In some commercial forms of this instrument the last fifteen minutes of the record is completely hidden by the chopping mechanism. If the melter is to use the record intelligently, he must know the trend as well as the level of his roof temperature, so the record must be visible for inspection.

AIR-UPTAKE TEMPERATURE MEASUREMENT

It must be re-emphasized here that this measurement, being considered as a class P item for routine control, is that of the wall temperature and not of the true air temperature. The latter can only be measured by special instruments such as a suction pyrometer, which so far are not suitable for continuous recording (*see* p. 70)

The most suitable point for measurement is that at which the highest temperatures occur. A definition of this point is impossible, but the Templeborough trials[1] (*loc. cit.*, p. 55) indicated that high temperatures are to be found in the air uptakes just above stage level. Thermocouples are even more objectionable in the air uptakes than in the roof, because the large cyclic variations over reversals would mean that the temperature gradient from the hot surface of the brickwork would be far from constant with time. In the air uptakes CO_2 and water-vapour absorption bands will cause serious errors during the waste-gas period if the instrument is sensitive to infra-red radiation. The conditions governing the choice of instrument are therefore similar to those governing the choice of the roof pyrometer and a similar instrument with a different range would be suitable. The barrier-layer cell type of instrument, however, is not sufficiently sensitive in the checker and uptake temperature range so that the choice is narrowed down to a vacuum emission cell instrument.

Both ends of the furnace should be recorded on the same chart to form a butterfly pattern (*see* Fig. 5) which readily indicates out-of-balance conditions. A solid pattern would be preferable (*see* Fig. 6), but suitable instruments are not made in this country. It may be possible to modify an existing automatic potentiometer instrument, so that the pen does not leave the paper when it moves from one record to the next, and this will be investigated.

GAS CALORIFIC VALUE

Possible choice of instruments is rather limited, but it is considered that the sigma-recording gas calorimeter is suitable for the requirements of reasonable accuracy with minimum maintenance. More elaborate instruments such as the "Simmance" or "Fairweather" may be used if desired, but it is only necessary to have a measure of gas quality and the more accurate instruments are not required for open-hearth conditions. A report on the use of the sigma calorimeter in open-hearth plants has been written by Lomas and Mayorcas[1] (*loc. cit.*, p. 44). Information on the use of other types of calorimeter in open-hearth shops is not available.

A homogeneous sample can be obtained by building the sampling probe into the gas main where there is a high flow rate and no danger of stagnation. In order to avoid an interruption of the sample flow at reversal, the sampling point should be sited before the gas valve. The sample line should be wide-bore gas piping laid on a gentle slope with a catch-pot for condensate at the lowest point. Any bends should be provided with plugs to facilitate cleaning. As the amount of gas used by the instrument is small, a large time-lag may be set up in long pipes with a danger of stagnation. In order to overcome this a high-velocity ejector pump can be fitted to the end of the sample line and the actual quantity required for the instrument drawn off through a short pipe. The gas pressure must be increased to about 20 in. water gauge by a booster pump, fitted after the filter for cleaning the gas.

Although it would be an advantage to obtain the calorific value of the raw gas, the practical difficulties of maintenance are too great, so the obvious alternative is to obtain the calorific value of definitely clean gas. Moisture content must also be definite and constant, and the most practical condition is saturated. Calorimeter errors introduced by gas temperature will be small (1% per 100° F.) if the gas is reasonably

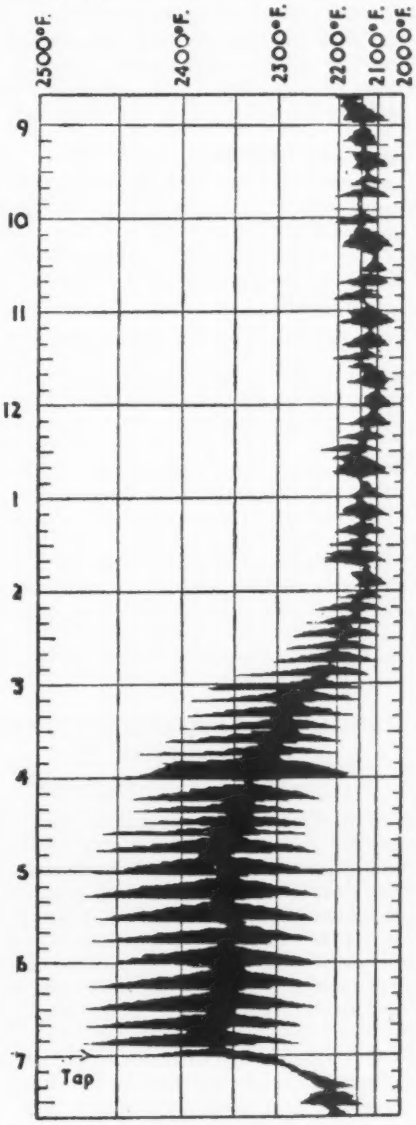

Fig. 6—Top checker brick temperature by photronic cell and automatic potentiometer (R. B. Sosman[5]).

cooled by the walls of the main sampling pipe. However, if the cool saturated gas is filtered, and then compressed, there may be a danger of mist formation. Serious errors due to latent heat of vaporization would be introduced if this mist was allowed to reach the burner, so a fine filter must be introduced in the high-pressure line.

GAS TEMPERATURE

If producer practice is good the gas temperature does not vary widely, or quickly, so that a sheathed thermocouple will give a fairly accurate indication. Errors due to radiation between the element and the wall of the gas main will be small, because the gas and main do not differ greatly in temperature.

Whilst most operators withdraw the thermocouple during the week-end burn-out, this is sometimes overlooked, and if a base-metal couple is subject to a temperature of over 1000° C., at frequent intervals, it soon deteriorates even if it is not destroyed.

GAS PRESSURE IN MAIN

This measurement will provide no difficulties if the pressure pipe is wide, and laid so that moisture drains to a catch-pot. As with flow measurement, the pressure pipe should consist of straight lengths and have suitable access plugs so that it can be rodded through periodically.

LIQUID STEEL TEMPERATURE

In this country the measurement is almost invariably made with a platinum/platinum–13% rhodium couple. The usual design uses a long steel tube insulated by carbon blocks (often old electric-furnace electrodes) to carry the couple wires. A steel end-block carries the replaceable silica sheath which covers the couple junction. The majority of the assemblies are fitted to a trolley to permit easy insertion of the couple to the furnace through a charging door. The technique is now well established as a routine measurement and details can be found in several articles,[20, 21] and the Pyrometry Sub-Committee of the British Iron and Steel Research Association will be pleased to help where advice is required.

MEASUREMENTS FOR SPECIFIC INVESTIGATIONS (CLASS R)

AIR PREHEAT TEMPERATURE

The temperature of a gas can only be rigidly defined when applied to a system in thermal equilibrium. When the gas is not in thermal equilibrium serious difficulties arise in measuring its "temperature" and different methods may lead to quite different results.[15]

In most practical cases the gas has a temperature different from that of the surrounding walls. A measuring instrument such as a thermocouple or thermometer, which is placed in the gas, does not measure the "true" gas temperature on account of radiant heat interchange with the walls, but rather a temperature which lies between the true temperature of the gas and that of the surrounding walls. It has been shown[9] that the errors in such measurements can be reduced by ensuring a high gas velocity past the measuring element. The error can be reduced still further by building the element with a small diameter and low emissivity, but in practice these quantities are fixed by practical requirements. Normal velocities in open-hearth flues fall far short of the values necessary for good heat transfer from gas to element. Errors in measurement using a simple thermocouple in the air preheat stream can amount to 200° C.

The logical outcome is the use of the high-velocity radiation-shielded thermocouple or suction pyrometer[1] (*loc. cit.*, p. 48).

A suction pyrometer consists essentially of a suitable thermocouple in a mullite sheath which fits into a central steel tube. A steel water-cooled jacket carries a refractory hood which projects over the thermocouple sheath. The hot gases are drawn between the thermocouple sheath and the hood by a compressed air or steam ejector. The actual gas velocity past the couple is adjusted so that an increase in velocity does not change the indication appreciably.

As the suction pyrometer is an unwieldy instrument, and it must be withdrawn during alternate half-cycles (to prevent blockage by waste gases), a permanent structure should be built on to the uptake which will guide the pyrometer into position and hold it when withdrawn.

If the pyrometer is used for preheats and waste-gas temperatures without withdrawal, blockage occurs after about six reversals, even if the refractory sheath survives, owing to slag particles in the waste gas.

The British Iron and Steel Research Association Physics Department is engaged on the design of a suction pyrometer which will use a radiation detector instead of a thermocouple. In at least one American plant this type of instrument is standard furnace equipment, continuously recording actual air-preheat temperatures.

As the meter is not in permanent use on a furnace, a portable instrument will probably supply the needs of the whole shop. The requirements are then for a very robust instrument that will maintain its calibration under severe conditions and withstand vibration without special mounting. It is doubtful whether any available instrument could fully satisfy the requirements, but a null method instrument will maintain accuracy better than a direct-deflection instrument under severe conditions of vibration and ambient temperature.

Carbon Dioxide in Waste Gases—The major difficulty in this measurement is obtaining a representative sample. It has been pointed out (*see* p. 62) that unless the in-leakage at the outgoing checkers is negligible the sample must be drawn from the down-takes.

Provided that a representative sample can be obtained there are several instruments available which will record the CO_2 content satisfactorily.

One class of instrument draws spot samples and measures the actual reduction in gas volume after scrubbing with caustic potash. These instruments are very reliable but the time-lag between sampling and recording is long compared with reversal intervals.

A better indication could possibly be obtained by using the type of instrument which measures continuously the thermal conductivity of the gas sample. The thermal conductivity of furnace waste gases is

closely connected to CO_2 content. The relatively new "infra-red absorption" method has not yet been adapted to suit open-hearth shop conditions.

FLAME RADIATION

It is very difficult to measure the radiation from the flame only, because the temperature of the furnace wall behind the flame will influence the indication. However, a useful signal may be obtained by fitting a total-radiation receiver into the front wall so that a thickness of several feet of flame is in the line of sight.

Very surprising results have been obtained in America using radiation instruments focused through the flame from the roof to the bath, and similar instruments,[16, 17] looking along the length of an oil flame from above the burner. It is claimed to be possible to show readily the effect of changing an oil burner or steam-atomizing pressure. Meters recording a function of flame radiation, variously called flame-power meters or heat-potential recorders, are in regular use in several American melting shops.

Preliminary results of works tests carried out by the Physics Department of the British Iron and Steel Research Association show that it is possible to obtain an indication of the heating power of the flame, with a total-radiation instrument, and it is hoped that a complete report will be available shortly.

FLAME EMISSIVITY

The emissivity of the flame can be evaluated if the radiation from different thicknesses of flame is measured so that the furnace walls do not interfere. Measurements of this type were made during the Templeborough trials[1] (*loc. cit.*, p. 129) using the narrow-angle radiometer which consists essentially of a total-radiation receiver and a water-cooled target. The apparatus is designed so that a definite thickness of flame can be located in the line of sight with the pyrometer looking through the flame at the target. This instrument is more of a research tool than any of the others recommended in this paper and it will only be necessary to use it for special investigations. The applications envisaged are the investigation of the effects of different fuels and preheat temperatures on the heating power of the flame.

GAS PRODUCERS

This paper is restricted to the study of instruments for open-hearth furnaces, but in furnaces fired with producer gas the required conditions of gas pressure, quality and flow will not be regularly met (particularly if fuel supplies remain bad) unless the producer plant is provided with sufficient instruments.

The following quantities should be metered and recorded, at the producer, in addition to the melter's instruments :

Air flow to fuel bed
Steam flow to fuel bed
Blast " saturation temperature "
Gas temperature at off-take
Gas pressure at off-take
Gas pressure in distributing main (this should be automatically controlled at the desired value as is done in most works).

The above instruments are all available as standard items of equipment and their installation on a producer will present little difficulty. Further discussion is outside the scope of this paper, as the subject is being dealt with by the Gas Producer Advisory Committee of the British Coal Utilisation Research Association.

OIL-FIRED FURNACES

The foregoing discussion applies to gas-fired furnaces, but is equally applicable to oil-fired furnaces if the instruments specific to gas-firing are replaced by similar equipment for oil.

Oil-fired furnaces in this country are, on the whole, considerably better-equipped than gas-fired furnaces, no doubt because there is no long experience to draw on with oil fuel on open-hearth furnaces, and the need for instruments has been more strongly felt.

Since oil firing requires an atomizing agent (usually steam), instruments for its measurement will be necessary in addition to those provided for the oil.

The instruments required are :

Oil meter (indicating, recording, and integrating)
Oil-temperature indicator
Oil-pressure indicator
Steam-flow meter (indicating, recording, and integrating)
Steam-pressure indicator
Steam-temperature indicator (with appropriate modification if air instead of steam is used for atomizing).

The temperature and pressure indicators may be standard articles with which engineers are familiar. It must be emphasized, however, that the steam-pressure indicator is only an indication of what pressure is available and should not be used as a measure of flow of steam as it may be very misleading in this respect. The relationship between steam pressure and flow depends on conditions in the burner and in the relative flow of oil.

There is an optimum steam flow for a specific burner and oil flow, so that a steam-flow meter is essential and its provision presents no difficulty as such meters are familiar to engineers. The question of oil metering is not quite so simple ; most oil-fired furnaces have an oil meter but the accuracy of some is very dubious.

CONCLUSION

The above report is an attempt at a general survey of the problems of applying instruments to open-hearth furnaces. To those without instruments, and to many who have already made a beginning, the equipment listed may appear formidable, particularly as the present supply position, both of instruments themselves and of trained maintenance staff, is by no means easy. The three years since the war have seen, however, an application of instruments to an extent which was previously undreamed of, so it may not be too optimistic to suggest that instrumentation even to the extent envisaged in this report, may become commonplace within a relatively short time.

Acknowledgments

The author wishes to express his thanks to Dr. A. H. Leckie for encouragement and advice, and to the Open-Hearth Instruments Sub-Committee of the

British Iron and Steel Research Association for helpful comment and criticism, during the preparation of this report.

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First Report of the Open-Hearth Instruments Sub-Committee

By F. L. Robertson, M.C., B.Sc., F.I.M.

SYNOPSIS

This report of the Instruments Sub-Committee deals with the necessity of measurement instruments for open-hearth furnaces. Both managerial and technical necessities are stressed. Individual instruments are not treated in detail ; this wide field is covered separately in the preceding paper by E. Rogers of the British Iron and Steel Research Association, which represents the views of the author and not necessarily of the Committee.

DEVELOPMENT OF INSTRUMENT USAGE

In a melting shop of eight furnaces working continuously, any one out of a total of 110 men may have the control of a furnace for some period. The responsibility of running a shop to his own, or somebody else's, ideas rests on the melting-shop manager. He has varying raw materials, varying fuels, various refractories, varying designs of furnaces, various steel to make, and all these men to help him. It is clear beyond any necessity for argument that he needs measurements as a means through which he can issue orders, and through which he can inspect how his orders have been carried out. As most of his measurements have a clock-time reference, instruments that record clock time simultaneously with quantity are necessary.

Formerly there were no instruments in melting shops and regulation of the process was carried out by the melter's eye and the engineer's design. Some melters and some engineers lived more dangerously than others, and so, as instruments started to be used in shops the urging principle varied with different shops. Shops which kept their roofs very successfully from melting by keeping their furnace passages and ports so small that enough gas to melt it naturally could not get into the furnace at any time, started measuring gas flow, furnace pressure, and so on, trying to achieve better outputs with the handicap of restricted passages. Shops where the furnace passages were big enough to let in enough gas to melt the roof easily, naturally started to make spy holes through which the roof could be seen and then started to measure roof temperature. In this way different instruments in different shops produced local priority lists that date back into past history. All links in a

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Mr. Robertson is Chairman of the Open-Hearth Instruments Sub-Committee.

chain are of equal importance, so the wise melting-shop manager starts making his chain link at a time from the beginning of his melt.

Fuel and Air Meters

How much fuel and air is he going to order to be carried on his furnace? To give his orders, or to transmit the orders of another individual or committee, he must have a fuel meter and an air meter. To compensate for the notorious leakage of the ordinary Siemens furnace he must calibrate the gas and air meter against the furnace leakages by a constant furnace pressure and exit-gas analysis on a furnace with specially sealed brickwork. When oil fuel is used the manager must issue orders as to the amount of steam in reference to the oil that is to be carried. Hence a steam meter becomes imperative.

Roof-Temperature Pyrometer

A manager, having settled the amount of fuel and air his furnace is to carry whilst the heat absorption of this charge is high, has to bestir himself to issue orders as to what is to be done when the rate of heat absorption of the charge drops, and the furnace gets hotter than the bricks will stand. The introduction of larger quantities of gas with consequent higher outputs made the regular five-minute, or more frequent, inspection of the roof by eye, necessary. Many an error of judgment resulted. The nervous strain resulting from the urge for higher and higher output on the one hand, and the danger of melting the roof on the other became too great, and the roof-temperature pyrometer was born.

A manager can now give orders for his fuel and air usage and keep his roof at any temperature, short of the melting point, he may want. His attention now passes to his steel and the chemical processes of his bath. The chemical processes are usually controlled by chemical analyses, and such analytical methods not normally regarded as coming within the field of furnace instruments. However, the chemical processes that are carried out in the furnace are so much better adjusted at particular temperatures, and tapping temperatures are of such importance, that the invention of immersion pyrometry was forced forward.

Secondary Instruments

These are the primary instruments through the medium of which a melting-shop manager can issue instructions, manage and inspect his shop. These primary instruments have a few handy, secondary hangers-on. A port pressure gauge read simultaneously with the gas meter, tells the manager the size of his gas port. Steam-pressure and oil-pressure gauges are handy, but subsidiary to flow meters. Checker-temperature pyrometers, whether measuring the temperature of the top or the bottom, are useful secondary instruments, but cannot really be regarded as primary melting instruments. For any one build of furnace, and for a fixed maximum supply of fuel, and for combustion procedure described above, there is nothing the melter can do to alter the temperature reading. These instruments are handy to check and correct out-of-balance checkers. They are also handy for those who prefer to reverse by checker temperature instead of time.

A draught gauge is a homely reminder of old days, but with the advent of fuel, air meters, and furnace-pressure regulators, whether manual or automatic, the draught gauge has ceased to be a primary melter's instrument. No manager issues fuel, air, and pressure orders without knowing he has enough draught to cover his orders.

INSTALLATION, MAINTENANCE, DISCIPLINE AND INSPECTION

The primary melting instruments, previously mentioned, cover the main instruments for steelmaking that have reached the usable stage in Britain. They seem such commonsense implements that the layman may well wonder why there is any need to advertise them. The reason for doing so is that installation, maintenance, discipline, and inspection do present difficulties, and the busy melting-shop manager knows this, and fears disaster. It is far better to run a shop the old way and develop craft to its maximum, than have instruments if they are installed wrongly, or not absolutely perfectly maintained. These two points are thoroughly appreciated by The British Iron and Steel Research Association who are prepared to advise prospective instrument users.

Discipline

Discipline is very much more difficult. A melter starts charging with a fixed amount of oil, steam, and air. His roof-pressure recorder is reading correctly. His eye has to remain on the roof-temperature recorder whatever other duty he is doing. At any time he may have to reduce his oil, followed by a definite reduction of his steam, followed by a reduction of his air, followed by a manual adjustment of his damper screw. The temperature now drops and all these motions have to be carried out again, in reverse. The matter becomes worse if the first adjustment was too much, or too little. The fact of the matter is, that the correct use of these commonsense instruments exacts a discipline that cannot be carried out. There are two ways out, one is to compromise, the other to make certain adjustments automatic. The compromises are matters for each individual manager, who, standing at his valves, must work out for himself the compromises he can accept in order to make the work possible for one man. The automatic controls are coming; there are at least two automatic roof-pressure regulators, and two roof-temperature/oil-flow automatic regulators on the market. There is, however, no automatic roof-temperature/gas-flow regulator. Neither of these solutions is wholly satisfactory. Compromises, such as running a constant air, not being too particular about the steam or the roof pressure, are all obviously bad. The automatic controls are quite costly and are still in the development stage, although there is little doubt that they will be widely used in the future.

Inspection

Inspection which should have been such a strong point has turned out in practice to be a very weak point. There are a number of reasons for this; often the instruments are so badly maintained that a

manager cannot take action, or the clocks keep such bad times that the correlation of different charts is difficult, or there is no attempt at a system of inspection at all.

The handling of these four difficulties falls to the melting-shop manager and remains part of his duties. What he cannot do by himself in his shop demands assistance, for which he must ask boldly and clearly. The writer of this article has made steel for years without instruments, and for years with instruments, and without the slightest diffidence or hesitation, and in spite of the difficulties mentioned, he gives his unqualified advice to all young melters to use measurement and, when possible, automatic regulation. To stand aloof and wait for the instrument maker or research department, cap in hand, to bring instruments and then condescendingly to use them, will lead to perdition.

In surgery it is the surgeon who has to do the operating. He may need anæsthetics, clean assistants, clean nurses, clean wards, and good clean instruments. He is the initiator and demander of all these necessities ; so, also, the melting-shop manager has to do the melting, and his similar duties and demands must be performed and met. This is mutual ; the manager has both to perform and be met. He can do neither if he does not know what to demand, and he is not likely to know what to demand, unless he measures.

SUGGESTED INSTRUMENTS AND THEIR USES

To sum up, for new steelmaking installations and the modernization of existing installations, the Open-Hearth Instruments Sub-Committee suggests the following list of control instruments. Items 1–6, 9, and 12 are considered essential to the proper working of the furnace : the remaining items are considered desirable. This list was circulated to the industry by B.I.S.R.A. some time ago, but is repeated here for the sake of completeness.

1. Automatic pressure control for the gas main
2. Gas meter
3. Air meter
4. Pressure recorder on the top of each of the gas chambers
5. Stack draught gauge
6. Furnace-pressure recorder
7. Automatic furnace-pressure regulator
8. CO_2 recorder for fuel gas
9. Roof-temperature recorder
10. Air-checker–top-temperature recorder
11. Timing device set to give a signal for reversal
12. An immersion pyrometer outfit

The instruments should be used in the following way :

1. The gas-main pressure control should be fixed at a pressure that will ensure the maximum quantity of gas that will be wanted at any time passing the valve-to-port resistance.

2. The gas meter should be used to show the maximum quantity of gas which the melting-shop manager considers can be burned in the furnace. He will order this quantity (to be referred to further as the maximum gas flow) not to be exceeded. Apart from this the gas meter will merely be used to record what has happened. The gas flow, itself, is not regulated to a constant value, but is controlled so as to produce the required conditions of roof and/or steel temperature in the furnace.

3. The air meter should be used to control the air flow to that rate at which the melting-shop manager thinks it is best to burn the gas.

4. The furnace should be so designed that, at maximum gas flow, a specified pressure will be attained at the top of the gas checker. An increase in this pressure at maximum gas flow indicates the making-up of the gas port and shows that the port has to be opened up.

5. The draught gauge should act merely as a recorder of what is happening and take no part in the regulation of the furnace.

6 and 7. The furnace pressure should be controlled either manually or automatically (normally by means of the stackdamper), so that under all conditions of gas flow, and the correct associated air flow, the pressure in the furnace is that which the melting-shop manager wants.

8. The producer should be run so that the CO_2 recorder always reads below, say, 5%.

9. The gas supply should be kept rigidly at the maximum gas flow until the maximum safe operating temperature shown on the roof-temperature instrument is reached. Thereafter it should be constantly adjusted, either according to the roof temperature, or according to the temperature of the liquid steel.

10. The checker-temperature instrument can be used for :

(*a*) Protection against overheating of the chamber
(*b*) Information
(*c*) Reversal, if the melting-shop manager likes this method

11. The time signal should be set so as to give a signal after last reversal, at such time as the melting-shop manager likes. It is an alternative method of reversal to temperature reversal.

12. The immersion pyrometer, along with the carbon content, should be used to fix the time ore feeding should commence and its subsequent rate, and also for controlling tapping temperatures.

INSTRUMENTS FOR OIL-FIRING OF OPEN-HEARTH FURNACES

With the advent, in this country, of the oil-firing of open-hearth furnaces the sub-committee recommends the following instrumentation which has proved very satisfactory on furnaces converted to oil-firing during 1946.

Oil meter (indicating, recording, and integrating)
Oil temperature gauges
Oil pressure gauges
Air meter
Steam meter } for the steam supply to oil atomizer
Steam pressure gauge }

The other instruments recommended are Nos. 5–7 and 9–12 in the list for a gas-fired furnace.

Though there is, as yet, in this country, little operational experience on oil-fired open-hearth furnaces, it can be said that the general principles of the rules given for the use of instruments on gas-fired furnaces apply with equal advantage to oil-fired furnaces.

IRON AND STEELWORKS ENGINEERING

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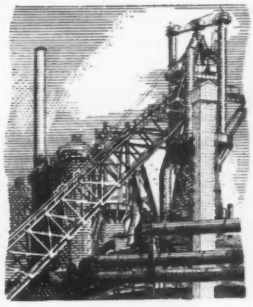

Ore Discharging

By G. T. Shoosmith, M.A., A.M.I.C.E., M.I.Mech.E., M.I.Mar.E.

A WIDE variety of equipment is in common use for discharging mineral ore from ships; it includes slewing and luffing jib cranes, rope-trolley transporters, man-trolley transporters, Hulett unloaders, and telphers.

The particular type of equipment used in any one installation is dependent on the general working conditions, type of ore, size of ship, and arrangement and location of stock pile, wagon roads, or hoppers.

It may be of interest to consider very briefly the limits of each of these broad types and the conditions under which they show to the best advantage.

SLEWING AND LUFFING CRANES

Until comparatively recently grabbing cranes of this type had not been built for a gross load in excess of 10 tons, but cranes of 15-ton gross load have now been constructed and there is no reason why cranes of 20 tons or even more should not be a practical engineering proposition. Such cranes are a most flexible type of discharging equipment in that they can operate over a large area without travelling the main structure and without adjacent cranes interfering with each other. Two such cranes can easily work out of the same hold and/or discharge to the same hopper; they can be arranged for overside discharge as into barges, or for the handling of other cargoes such as scrap, steel sections, timber, etc. Where, however, a comparatively straight-line discharge is required the slewing type of crane cannot compete with the transporter either in speed or in economy. The speed with which the grab can be transferred from one point to another is limited in practice owing to the setting up of dangerous swinging of the grab. The rotating portion of the crane represents 60 to 70% of the total weight, and this mass requires elaborate mechanism to control its radial acceleration and deceleration.

The radial and luffing movement of the jib, combined with the long length of rope between the jib head and the grab, enables a skilful operator on a crane of this type to throw his grab well under the coamings of ships, hence reducing the labour required for hand trimming. The ability of adjacent cranes to work out of the same hold is a favourable feature where it is necessary to deal with awkward ships; such ships frequently have one or two particularly bad holds, with either a shaft tunnel or deep tanks, or possibly a long throw under the bridge. Two cranes can be concentrated in these bad holds in order to keep pace with the other holds.

Figure 1 shows slewing and luffing cranes discharging iron ore.

ROPE-TROLLEY TRANSPORTERS

Machines of this type are suitable only for straight-run work from ship to hopper. They have the advantages that the structure is comparatively light and simple, and extremely high operating speeds can be obtained. As an example, a 10-ton gross-load machine of this type, recently seen by the author in the U.S.A., had on a number of occasions discharged at the rate of 600 tons/hr when breaking down cargo, *i.e.*, when taking the cream off the top of the hold. This machine had a hoisting speed of over 1000 ft/min, the hoist motor being of 500 h.p., and the peak h.p. for the machine being in the neighbourhood of 1100. The cross-travel speed of the trolley was also 1000 ft/min on this particular machine, and the peak h.p. demand occurred at the moment of accelerating both the hoist motion and the cross-travel motion. The total weight of the machine was about 250 tons.

The disadvantages of this type of machine for normal work, however, are serious. The driver cannot be positioned so that he can see properly both into the ship and into the discharging hopper. It is impossible to arrange any satisfactory mechanism for turning or slewing the grab and so the motion of the grab is limited to the straight-line path of the trolley. Practical considerations, covering the hoisting and traversing ropes, limit the length of the trolley travel. A special construction of non-twist rope is required, and the cost of rope maintenance is

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Fig. 1—Four 7½-tons gross capacity slewing and luffing cranes in operation. (The property of Messrs. Rea, Ltd., Liverpool)

comparatively high. The proof that these disadvantages are widely recognized is found in the fact that, despite the comparatively low first cost of this type of machine, it is rapidly disappearing from use wherever continuous discharging is required.

MAN-TROLLEY TRANSPORTER

By this is meant a transporter on which the driver travels in a cab attached to the trolley and on which the trolley is traversed by a self-contained drive without the use of ropes. Man-trolley transporters can be divided into three distinct types. In the first the grab is suspended direct from the hoisting drums on the trolley. In the second, means are provided on the trolley for twisting the grab through 90° so that the grab pans can be opened either athwartship or fore and aft. This can be accomplished either by mounting the hoisting drums on a slewing platform on the trolley proper, or by the use of a slewing " bull ring " to which the dead ends of the hoisting ropes are attached. The third type, commonly referred to as the slewing-jib transporter, has what is virtually a small-radius slewing crane underslung from the trolley.

It is interesting to note that although slewing-jib transporters have been constructed in the U.S.A. they have been out of favour in recent years and most heavy transporters, newly built, and being built, are either of the straight type or incorporate some form of grab-twisting gear. The reason for this is that by far the greater proportion of the bulk material discharged from ship, in the U.S.A., is handled on the Great Lakes from lake vessels which are equipped with a large number of comparatively narrow hatches. The width of these hatches is normally from 8 to 12 ft, and the grab must be lowered through them in the athwartship position and, once in the hold, its freedom of movement is strictly limited. These considerations do not apply to discharging from any normal type of sea-going vessel.

Continental ports have operated almost every type of transporter—rope-trolley, man-trolley (straight- and slewing-jib)—and in their experience the slewing-jib type has proved the best. It is true that the slewing-jib equipment involves some extra weight on the trolley, and additional complication of the machinery, but it achieves three important advantages. Firstly, it enables the grab to be placed more accurately in the hold of the ship, and to be swung under the coamings of the hold into awkward corners, when required, thereby reducing trimming. Secondly, it can frequently enable two transporters, working close alongside, to discharge out of the same hold, which, as previously mentioned, can be of appreciable benefit under certain conditions. The third and chief advantage of the slewing-jib type is that the driver can see his grab in the hold of the ship at all times and avoid causing damage. It is not possible for the driver of any other type of machine (except the Hulett) to see his grab when it is swung under the near or quayside coamings of the ship. When discharging direct from ship to hopper it is frequently possible for the slewing-jib type to work a large proportion of the hold without travelling the machine more than a few feet. This is economical in power and reduces the wear-down of the traversing and travelling wheels and rails. This advantage is less pronounced when considering wide-span transporters for discharging from ship direct to stock pile ; in such cases the additional weight of the slewing gear may be a slight disadvantage as it has to be accelerated and decelerated when moving the trolley.

Man-trolley transporters, at the present time, are replacing other types of discharging equipment both in this country and abroad, and it is proposed to comment on their detailed design later in the paper. It may be of interest, however, to mention that in the U.S.A. a man-trolley transporter of recent construction was timed to complete 41 cycles in 30 min. This machine had a gross capacity of 35 tons and was discharging to a narrow stock pile

Fig. 2—Man-trolley transporter of 35 short tons gross capacity, installed at the Ford Motor Company's River Range Plant, U.S.A.

approximately 100 feet behind the centre-line of the ship. The working speed at that time, which was during the breaking down of the cargo, was equivalent to 1100 tons/hr, the hoisting speed being 500 and traversing speed 1100 ft/min. A recently constructed straight man-trolley transporter is shown in Fig. 2.

HULETT UNLOADER

The general design of the Hulett unloader is well known. It comprises a rotatable tower to the lower end of which the grab buckets are attached, the tower itself being suspended on parallelogram arms carried on a traversing framework. The machine is peculiar to the Great Lakes of America, where it was considered at one time superior to any other form of unloader. The grab pans at the lower end of the tower are arranged for eccentric opening; by this it is meant that when the pans are open, one pan retreats much further than the other. On the larger machines the out-reach of this pan is approximately 15 ft from the centre-line of the tower. When the tower and grab are lowered through the narrow hatch opening of a Lake vessel it is possible for the driver to rotate the tower to any position desired, and to reach into the wings of the ship with the out-thrust pan, with beneficial effect on the amount of trimming required. It can be said that the Hulett machine was born out of the limits of the Great Lakes ships and absence of tide. It should also be noted that, unlike any other grabbing machine, the grabs of the Hulett can be positively thrust down on to the material in order to obtain a full bite. The driver sits in a very confined cabin, built into the bottom of the rotating arm, immediately above the grab pans, where he has a close-up view of the grabbing operation. He has five principal controls to operate: long travel, cross traverse, boom raise and lower, column rotation, and grab opening and closing. The disadvantages of the Hulett machine are perhaps more obvious than its advantages, and they are such as to rule it out of court in any save the most exceptional circumstances. It is enormously heavy, its machinery and control equipment complicated, and the inertia of the moving parts, and hence the power consumption, is excessive. Its practical cycle of operations is strictly limited. It is a full day's work to change the grab pans, so that it is out of the question, for instance, to use two different types of grab for two different types of bulk material. Whilst the driver has the finest view of his grab in the hold, should he make an error of judgment he can strike the ship with the full weight of the grab, the rotating tower, etc., behind the blow. Perhaps the principal limitation of this type of machine is the range which the parallelogram arms can give to the grab. It will be found that to make allowance for any appreciable rise and fall in tidal conditions, plus the depth of hold of large sea-going ships, necessitates carrying arms of immense length. This, however, greatly increases the weight.

TELPHERS

The author is aware of only one telpher installation of any size handling ore, and this is in the U.S.A. The telpher is in effect a variant of the man-trolley transporter, in which the main framework is rigidly fixed, but the trolley can be taken round curves, through points and crossings, and so forth, on similar lines to railway tracks. It can usually be employed where discharge is from a ship to a number of awkwardly placed hoppers, or storage bins, and it is so used, widely, in this country for handling coal.

The speed of operation is somewhat limited if curves have to be negotiated, and any form of slewing jib is ruled out by the need to balance the load. For normal ship discharge the telpher has no advantages and many drawbacks.

DEVELOPMENT OF NEW PLANT

Before discussing the detailed design of normal unloading plant, brief consideration should be given to the possibilities of the development of new types of plant. It is evident that the present method of unloading by grab leaves much to be desired, the modern tendency in all forms of material handling being to aim at continuous rather than intermittent flow. The obvious line of attack for discharging bulk material such as ore from a ship is the bucket elevator. Bucket elevators of large size have been built for handling coal in which the elevator itself has been mounted in a form of gimbal ring and given vertical movement to enable it to reach down and into the wings of the hold as the cargo is discharged. A large machine of this type, designed and constructed in Holland, was used in this country for bunkering ships during the recent war. After trial and tribulation this machine was made to work, and it did at one time achieve an output of 350 tons/hr on large coal, working out of an open hold in a barge, and delivering *via* conveyor to the ship's bunkers. The buckets were approximately 4 ft wide × 2 ft deep and were of massive construction. More recently an American engineer has developed an idea for using a bucket elevator of this type, attached to the bottom of which is a pair of grab pans, with the object of scraping the material in the hold towards the bucket intake. It can only be said that experience of machines of this type, however desirable they may be in theory, prove them not to be a practical proposition for normal work. It is found, as with the Hulett, that to cater for the rise and fall of the tide through the depth of hold, the height of the elevator and its carrying mechanism involves an immense structure. The wear and tear on the elevator parts is severe even when handling material such as coal, which is comparatively friable and has lubrication properties: with the handling of iron ore, the maintenance required would be very great. It will also be found that to transfer the material from the elevator to hopper, stock pile, or bin, is by no means an easy matter; it involves elaborate feed spouts and conveyors, tripping gear, etc.

FEATURES OF DESIGN

Since the man-trolley transporter has established itself as the principal type for ore discharge, it is proposed to enlarge on certain design features with particular reference to machines of this type.

STRUCTURE

The structure must be stable and robust, yet as light as possible. This can be better achieved by wide use of electric welding and, at added cost, by use of high-tensile steel. The author favours welding in preference to riveting, in every possible instance, since it not only reduces weight (by elimination of attachment flanges, etc.) but also provides a positive protection against the joint loosening, in time, due to vibration or interface corrosion.

Frequent references have been made to the possible fatigue of welded joints in large structures which are subjected to severe alternating stresses; this, more particularly in the U.S.A., where trouble has been experienced with welded ships' hulls. The use of correct design and procedure eliminates such failures, and there is ample evidence that good welding will stand alternating stress better than riveting.

The use of high-tensile steel is harder to justify, but in some cases it may simplify carrying-wheel arrangements, and give other secondary advantages outweighing its higher cost.

It will be noted that the word " stable," rather than " rigid," was used previously to describe the ideal structure, meaning that the structure must be free of excessive deformation or vibration under the extremes of loading, without any attempt at making it too rigid. A certain amount of " give " is beneficial, and this can be built into a comparatively simple structure of this type by providing members of adequate, but not excessive, size for the duty, and by avoiding large gusset connections. A point to be specially catered for in high-speed transporters is the bracing of the main structure in the traversing plane, as, here, high acceleration and braking of the heavy bogie unit can set up very high momentary loads. Sooner or later in the life of every transporter the driver will make a mistake, or a control will fail, and the bogie will run into the end stops of the traverse at full speed. This will put an excessive strain on the traverse bracing of the main legs, and a condition arises in which an ounce of elasticity may be worth a pound of rigidity. To illustrate this point—one modern and exceptionally rigid transporter failed shortly after erection owing to the bogie over-running the stops, resulting in the shearing of the transverse leg-bracing connections. Conversely some 15-ton Continental transporters, which have more than once been subjected to similar strains in their 20 years of life, have never shown any sign of failure, although the structure is so flexible that it is almost impossible to stand on the traverse walkway without holding on when the bogie is stopping or starting.

Emphasis should be made of the necessity for a good end-cushioning device on the traverse motion. In the U.S. the Mead-Morrison Corporation have developed an excellent buffer, consisting of a set of spring-loaded rails above the bogie wheels. With this device the bogie, if it over-runs, is stopped by the progressively increasing resistance set up as the leading wheels try to force the upper and lower rails apart. In fact this is the only buffer the author has yet seen on a transporter which is designed for the work. Spring buffers often prevent serious smash-ups, but are usually carried away in the process, and hydraulic buffers are usually locked solid just when they are wanted. Some form of liquid spring, as developed for aircraft undercarriages, is a likely solution, as it is relatively light, it gives long travel with progressive resistance, it is simple and cannot fatigue. We are experimenting on these lines, as precise calculation of the deceleration is possible with a liquid spring, and it should prove possible to design the buffer so that even damage due to grab-swing is eliminated.

A point to note in connection with the structure is that sections should be arranged to shed water, *i.e.*, channels should be arranged, where possible, backside uppermost, and drain holes should be provided where it is impossible to arrange natural drainage at joints. Enclosed compound sections and light lattice girders should be avoided as they are difficult to scale and paint. Broad flange beams can now be used for members previously requiring a built-up section.

MAN TROLLEY

Except in the case of wide-span transporters (commonly called " bridges ") there is no point in designing for a much greater traversing than hoisting speed. A transporter of recent build abroad has a traverse of over 1000 ft/min and a hoist of 250 ft/min. The result is that, when discharging from a ship, the traverse motion cannot be started until the grab is nearly up to the main cross bracing on the structure, and very little time is saved as compared to a similar machine with a traverse of 500 ft/min, on which the driver can commence to traverse as his grab is clearing the ship's coaming. Very high traversing speeds may be desirable for wide-span bridges, and if high acceleration is also required (as is desirable), sanding gear may be necessary to prevent skidding in wet weather. This should, however, be avoided wherever possible as it causes wear of wheels and rails, and there is a danger of the sand getting into other parts of the machinery. There is little to be said for mounting the trolley axles in horn guides, with carrying springs, on the lines of locomotives. This lends some cushioning to the structure against shock loads, and tends to insulate the trolley and its gear from vibration due to inaccuracy of the traversing rails, and rail joints; but this appreciably complicates the drive, and vibration is almost eliminated if the rails are welded at the joint, as is now becoming common practice.

High acceleration is the principal aid to good working for both the hoist and traverse motions. It is more important than high maximum speed. On normal slewing cranes and on rope-trolley transporters, load balancing is a great aid to high acceleration without high current peaks, and it can be calculated that in many cases such balancing pays a dividend. The problem on a man-trolley transporter is more difficult to solve, though load balancing can be achieved even on a full slewing unit. It should be said, however, that fully balancing the grab results in a 40% reduction in installed motor and control gear h.p. for the same duty and a 30% reduction in the power input to the hoist motion—an appreciable amount where peak loads of 500 to 1000 h.p./unit are normally required.

It goes without saying that the moment of inertia

of all rotating parts should be kept to the absolute minimum consistent with strength. It can be shown that upwards of 65% of the power input is absorbed in the acceleration of the rotating parts of the hoist motion of the average high-duty unit.

For the same reasons the overall weight of the trolley must be kept to the absolute minimum consistent with stability, and wide-track trolleys are beneficial on this account. Any extra trolley weight requires added peak power input to accelerate, added braking power to stop, added rail and wheel wear, and added strength to resist transverse loading.

The slewing structure of the trolley should be provided with jacking pads, mating with pads on the fixed structure of the trolley. These are of value for lifting the cab assembly for overhaul of the thrust bearing ; and they can also be designed to act as stops to prevent the cab dropping, in the unlikely event of the centre post breaking.

The trolley should be fitted with renewable slippers adjacent to the main traverse girders, so that the trolley cannot be appreciably displaced, relative to these girders, even if the wheels leave the rails.

ELECTRICAL EQUIPMENT

The remarks under this heading will, it is hoped, promote a useful discussion. Handling bulk materials in various ports at home and abroad, my own company operates transporters and cranes of many types, driven by every type of prime-mover : steam, diesel, hydraulic, and electric. Units of the electric type are working on D.C. voltages from 220 to 500, on 2-phase, 240-V, and on 3-phase, 400-V. There are also seven large slewing cranes working on Ward-Leonard control.

In the U.S.A. the use of D.C. on transporters is almost universal, using slow-speed mill-type motors and massive mill-type controllers. On the Continent, also, D.C. motors have been generally favoured. The author went to some trouble to discover why the U.S. continued to adopt D.C. even in their latest units, and gathered that it was for the following principal reasons :

(*a*) Ease of speed control
(*b*) Availability of D.C. power at steelworks and docks
(*c*) To incorporate existing designs of D.C. mill equipment (the argument being that since such unloaders worked in steel mills their equipment should be of mill type)

Development in this country has been on rather different lines. On the one hand we have tended toward the use of 400-V, 3-phase A.C., and on the other we have developed for large drag-line and excavator equipments the use of 3300-V, 3-phase A.C. input using specially protected trailing cables and M.G. sets, or Ward-Leonard sets, for the input to the operating motors. For a truly mobile unit the H.T. trailing cable has obvious advantages in the larger sizes. A 1000-amp, 400-V trailer cable would be a nightmare, whereas a 3300-V cable for the same power is comparatively handy, and no one can gainsay the smooth control which the Ward-Leonard system gives for such work. The same arguments cannot, however, be used where a transporter on rails alongside a quay is concerned. Current collection can be arranged on contact strips which are indeed more convenient and cheaper than trailer cables requiring automatic winding devices, etc., and 1000, 2000, or 3000 amps can easily be handled by such strips with carbon-brush pick-ups.

It is argued in favour of D.C. that to obtain the same starting torque an A.C. motor of larger nominal power is required, and, further, that the torque of the A.C. motor is an inherent feature of its design and cannot be exceeded without " pull-out " and stalling.

Nevertheless there are now available excellent control schemes for slip-ring motors, bringing the performance of these well into line with series D.C. motors. What interests the crane operator, as distinct from the electrical engineer, is not the installed name-plate power of the motors, but their first cost, consumption, and maintenance cost.

As to first cost, it will almost invariably be found that the A.C. drive is cheaper, more particularly where rectifier plant or Ward-Leonard equipment is necessary for the D.C. system. In our experience, the A.C. drive is more economical and we have some 7½-ton gross grabbing cranes which, over an extended period, have discharged 3·5 tons per kilowatt-hour (compared to similar D.C. units averaging 2·5). There can surely be no doubt that the transformer/slip-ring-motor combination is far superior to any D.C. combination so far as maintenance costs are concerned.

As to torque limitation, if the A.C. motors are designed for 2·5 × full-load torque, at starting, they are already capable of exerting the maximum safe load for the structure, and, as grabs are liable to get buried and to catch up under coamings and other ship obstructions, this torque limitation is a valuable safety factor rather than a drawback.

Finally it should be mentioned that for grabbing work, there is no advantage in lowering at appreciably greater speed than that used for hoisting. The average lowering distance is not such as to give any appreciable benefit from so doing, and, conversely, too high a lowering speed is apt to cause damage to grabs and ships, and to be a danger to the trimmers working in the hold. It will often be found that for the essential high acceleration of the motions of a grabbing crane the A.C. drive gives advantages over D.C. in lower moment of inertia of the rotating parts, and lower over-all weight of the bogie, this being more pronounced if use is made of 1000-r.p.m. motors.

Some recent grabbing cranes designed by the author are equipped with totally enclosed 400-V, 3-phase slip-ring motors and Igranic C.T.L. control gear. This system incorporates a sequence control independent of any subsidiary time or current relay. The driver's controls are of the face-plate type, specially designed to give finger-light operation and move in the same direction as the desired response. In operation, all motions on these cranes are extremely smooth, acceleration is high and free from jerkiness, and each motion can be thrown from full speed ahead to full speed reverse without shock or excessive peak current. The contactors are D.C. energized, and clutches and brakes are operated by thrustor. As a matter of interest, one of the drivers of the Ward-Leonard cranes was detailed to drive the new A.C. machines for two weeks, and at the end of this time

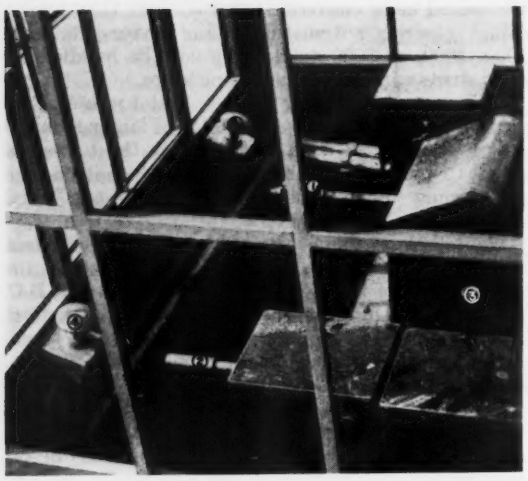

Fig. 3—Inside view of driver's cabin of Purfleet 7½-ton crane, showing (1) hoist-and-slew controller with clutch-control button; (2) luff controller; (3) travel controller; (4) dig button; (5) cut-out button

he reported that from his operating experience the A.C. control was as satisfactory as the Ward-Leonard.

Apart from the high first cost, weight, and additional maintenance of the Ward-Leonard system, it has a further serious drawback in that the continuous hum of the motor and generators hinders the driver from hearing the hatchwayman's orders. The reduction of machinery noise should be specially studied for this reason. Further, if the background noise level is low, the driver can more easily hear any other sounds which may denote faults in the machinery.

It cannot be over-emphasized that for continuous spells of driving on high-duty grabbing cranes, the controls must be well placed, simple, and finger-light. The hoist and slew should be interconnected so that one lever serves both purposes. In the case of our latest cranes, this same lever has a push button which operates the hoisting clutch for opening and closing the grab. In the case of a man-trolley transporter with slewing motion, the combined slew-and-hoist lever should be placed close up to the driver on his right-hand side and the traverse lever on his left-hand side. For all normal operation of the crane, the driver need never take his hands off these controls. Figure 3 shows the driver's cab on an A.C. crane.

As regards the motors themselves, it is essential that they should be totally enclosed, but there appears to be no valid argument for using the slow-speed heavy-carcase mill type of machine, and a standard industrial type totally enclosed slip-ring machine, properly rated, is perfectly adequate for the heaviest crane duties.

Modern grabbing cranes are frequently fitted with double-motor drive to the hoist motion, that is to say with a separate motor and drive for the closing-rope and holding-rope drums. This system probably originated from the difficulty of manually operating a large coil or other type of friction clutch. Many cranes, however, are now fitted with thrustor-operated clutches, mechanically or electrically interlocked with the holding brake, and, as has already been described, the operation of opening and closing the grab can, by this means, be controlled by a push button on the hoist lever. It is possible by means of automatic cut-outs to arrange for the grab to open and close by one momentary push on the button, though this is a feature which for a number of reasons is not really advisable. The fact remains, however, that in the author's opinion single-motor and coil-clutch drive is superior to two-motor drive. There is only one motor and set of control gear, no load-sharing provision is necessary, and the first cost is lower. The coil clutch, if properly designed and maintained, gives trouble-free service for many years. If there are electrical engineers who can put forward sound arguments in favour of two-motor drive, the author has yet to meet them.

MAINTENANCE

The maintenance aspect should be specially considered in the design stage. It is possible by so doing to reduce appreciably the time taken to carry out overhaul and repair, and to reduce the quantity of spares normally held in stock. For instance, the number of types of contactors in the control gear should be kept to the minimum and, similarly, the number of types of solenoids or thrustors, brake wheels and blocks, controllers, ropes, wormboxes, resistance units, sheaves, traverse and travel wheels, etc. The more important mechanical parts should be jig-drilled and made to gauge so that they are interchangeable as between machines and spares. It is often possible to use the same size of motor for two or more drives on the machine.

Removable panels should be incorporated in the machinery houses with pulley blocks and runners so disposed that the main parts of the machinery can be easily removed and lowered to the ground.

Resistance banks for the control units should be mounted externally to the houses so that their heat does not cause deterioration of the other equipment. There should be proper access behind, as well as in front of, all control panels. Wherever possible cabling should be run in heavy-gauge galvanized conduit with gas-thread connections, and properly tabbed and labelled in accordance with the wiring diagram.

As a general rule no cast iron should be used for any part of a grabbing crane. Wherever possible each complete motion, with its gearing, should be mounted on a combined bedplate so that alignment is ensured even if the structure flexes.

Lubrication nipples should be brought to points of easy access, and grouped and labelled. This particularly applies to such items as the bogies, on which the normal lubrication points are frequently inaccessible. Gear cases should be provided with dip sticks in preference to sight glasses, which are often useless with heavy gear oil.

Houses should be of plain plate, not corrugated iron, which always lets in water and draughts and becomes loose. No timber should be used as this saturates with oil and becomes a serious fire danger Drivers' cabins should be lined with removable fire-proof insulating boards.

ROPES

The design and layout of the ropes on cranes is a most complicated subject and can only be briefly touched on in this paper. It is sufficient to say that the whole secret of long rope life lies in providing the highest possible sheave/rope diameter ratio. For normal cranes this ratio is 20 to 25, but increasing this ratio to 50 more than doubles the rope life. This applies to both the drums and the sheaves, and it is necessary for maximum life to ensure that the grooves on the drums and sheaves are correctly maintained and do not become scored or chipped. Any attempt at increasing rope life or safety by using larger ropes at the expense of the sheave/rope diameter ratio is doomed to failure. A rope with a factor of safety of 5 and a sheave/rope ratio of 50, will frequently give better and safer service than one having a factor of safety of 8, and a sheave/rope ratio of 30.

GRABS

Here again the subject is one which can only be very briefly commented upon. The author has discussed grab design with operating engineers in many countries, and finds the wide divergence of views surprising. Unfortunately, even when considering one particular material such as iron ore, no one design of grab can be found which suits all requirements, since ore may vary widely in weight and, what is more important, may vary widely in size. For grabbing comparatively small-sized Swedish ore the simplest and most robust type of grab can be used with a limited out-reach, whereas for grabbing large ore a wide-spread grab is almost essential and it has the added advantage that if properly handled on a suitable machine it can greatly reduce the amount of trimming required in a ship.

The widest use can be made of welding, which has been found to withstand wracking and twisting much better than riveting. It is advisable to rivet the lip plates as these require periodic removal for fairing and building up the cutting lips. We have found a work-hardening manganese-alloy welding rod ideal for the building-up of worn lips.

For handling large material the closing purchases in the grab should be not less than 4 to 1. There has recently been developed, in Holland, a wide-spread ore grab of the level-cut type, on which the closing purchase can quickly be altered so that the grab can be closed rapidly in easily grabbed material, and closed slowly at maximum purchase in difficult material, or when cleaning up on the tank top of a ship.

Wide-spread grabs of the Priestman level-cut and Voorwinde type are not only more efficient in difficult material but also have very low headroom when open, enabling them to be swung into 'tween-deck spaces.

In general, the net load is approximately 50% of the gross load in the case of heavy-duty grabs. Thus a typical Priestman level-cut grab of 12½ tons gross has a capacity of 6½ tons net, and the Voorwinde ore grabs of 12,500 kg, employed in the Stocatra plant, have a net capacity of 6300 kg. The weight of the grab is, of course, decided by the requirements of robustness of design, and ability to dig. We have increased the net-load/gross-load ratio to nearly 75% in the case of some light-welded grabs at one Thames depot, but these are suitable only for work in small coal which can be easily grabbed.

A Voorwinde ore grab of 15 tons gross, working in the hold of a ship, is shown in Fig. 4.

On man-trolley transporters it is not possible to incorporate a grab-steady rope or tag line, and it is therefore advisable to space the closing and holding ropes as widely as possible in order to prevent swinging of the grab, either during slewing or twisting, or by point contact of the grab in the ship.

Quick and simple means should be provided for changing the grab, as this may be required at any time of the day or night, because of failure of the grab or the necessity of fitting a small grab for working in an awkward part of a ship. In the U.S. the main hoisting ropes are commonly reeved through the grab, and are attached on the latest machines to the winding drums through key slots cast in the drums, the end of the rope being formed into a ball which easily slips into the key slot. This means that if the rope adjacent to the grab becomes chafed, as frequently happens, the whole length is scrapped, and this involves about half-an-hour's work for 4 men to change over 2 closing ropes on a large unit. On some Continental ore transporters a simpler method has been evolved and used for a number of years. The closing-rope sheaves at the jib head are of the combined rope and chain type, and the main closing ropes are attached to the grab closing ropes by means of two Bordeaux connections and a special stud link. This stud link is arranged so that one side of the link and the stud can be removed by a key, and the change-over of the grabs can therefore be carried out by one man in a few minutes. Such an arrangement can be incorporated only on a man-trolley transporter of the slewing type without sacrificing a considerable

Fig. 4—A 15-ton Voorwinde ore grab in operation

height of lift, since the Bordeaux connections and the stud links cannot be accommodated on the winding drums without considerably increasing the drum width and weight.

SUITABLE SHIPS

The importance of using suitable ships, from the standpoint of economical and rapid discharge and turn round, has not been sufficiently appreciated in the past. A few actual examples of discharging times may be enlightening. At one particular installation abroad the equipment consists of two 35-ton gross transporters and two 15-ton gross transporters. These four machines have regularly discharged a special 24,000-ton D.W. ore carrier in 20 hr from start to finish, which is equivalent to 1200 tons/hr. The best recorded performance in discharging this particular ship was 16 hr 45 min. The average time taken by the same plant to unload specially converted Liberty ships (with 'tween decks and other obstructions removed) was 19 hr for 9500 tons, equivalent to 500 tons/hr. The average time with the same equipment to unload a standard Liberty ship was 51 hr, equivalent to only 186 tons/hr. These times, striking as they are, represent only part of the picture. The cost of the discharging operation, comprising operator's wages, power consumption, and maintenance, are increased roughly in proportion to the hours taken, and the unsuitable ship requires special grabs to get into the spaces alongside the shaft tunnel, and extra gangs of hand labour for trimming out under-deck spaces, shaft-tunnel recesses, 'tween decks, material lodging on stringer bars, and material lodging on vulnerable deep tank covers. In addition, the unsuitable ship may be considerably delayed for the carrying out of repairs to tank tops, man-hole covers, spurketing, tunnel casing, stanchions, ladders and, not infrequently, deck erections. The larger the grab the more serious the damage under these headings may prove to be.

In the carriage of coal it has long since been accepted that the most economical method is to employ specially built self-trimming colliers which return to their loading point in ballast. A study of the composite picture of shipping, loading, and discharging has convinced American operators, both on the Great Lakes and on the Atlantic seaboard, that a similar state of affairs exists in the carriage of ore. The latest American ocean-going ore carriers have a dead-weight carrying capacity of 24,000 tons and a speed of 16½ knots loaded, and 17–18 knots light. The holds are about 35 ft wide, the same width as the hatches, and are fitted with hinged, steel, hatch covers. The fore-and-aft and 'thwartship bulkheads of the holds are of corrugated construction and extremely massive to withstand grab contact. The wide wing tanks, which run the full length of the holds, are used for ballasting on the return journey. There are no ledges or obstructions of any description in the hold and any point is easily reached by the grabs.

On the latest self-trimming colliers wing tanks are used which form the dual purpose of trimming the coal automatically to a point where the grab can easily reach it, and providing a space for water ballast. Sliding steel hatch covers are used, deck fittings are well shrouded and reduced to a minimum, and masts, complete with rigging, can be telescoped down to within 6 ft of the deck.

The cost of hand trimming a suitable ship represents some 30% of the all-in cost of discharge. It can mount to 50 or 60% in the case of particularly unsuitable vessels. This is apart from the cost of repairs to the vessel, and the increase in freight rate which must result from delay in discharge and for repair.

However desirable the provision of suitable ore carriers may be, it is appreciated that with the present world shortage of ships there is no immediate likelihood of special vessels being provided for all requirements. There appears, however, to be no reason why some existing vessels should not be converted so that they are practically self trimming; and at the same time tank tops, ladders, stanchions, etc., can be repositioned or strengthened to withstand grabbing duty. Figure 5 shows the principal changes in this connection which could be effected to a standard Liberty ship to achieve these ends. A few ships have been partly converted on these lines in the cutting back of the 'tween decks and the shrouding of the deep-tank covers. The additional work now suggested includes a false ceiling over the top of the shaft tunnel, and the fitting of hopper tanks round the bases of all holds which will trim the ore automatically to within the reach of the grab.

The interesting point to note is that the provision of all these modifications results in a loss of less than 5% of the original cubic capacity of the holds.

MECHANICAL TRIMMING

Whilst the provision of suitable ships will go a long way towards reducing the trimming required, it will be a long time before any appreciable proportion of the tonnage dealt with is carried in such ships. Methods of mechanical trimming of ore are therefore of the utmost importance. Mechanical trimming can give three major benefits.

Firstly, it reduces the excessive cost of manual labour, and such labour is very difficult to recruit. Secondly, it reduces the time required to clean up the cargo, and hence improves the whole efficiency of the shipping and discharging operation. Thirdly, by removing the ore from awkward pockets and transferring it to the centre of the hold, it eliminates the necessity of swinging or throwing the grab into these spaces, and hence reduces the damage both to the ship and to the grab itself.

The problem has, as yet, been only partially solved, but it is of interest to consider the various methods so far attempted and now actually being employed.

Probably the first serious attempt to tackle the trimming of bulk cargo such as ore and coal was the use of hand-controlled portable ploughs to haul out cargo by attaching a line to the plough through a snatchblock in the hold, and thence to one of the ship's winches. Ploughs rigged in this way are frequently used for trimming such cargoes as grain, but for coal and ore, and other heavy lumpy material, they have not been very successful. The attachment of the snatchblocks is usually difficult; the haulage wires interfere with the operation of the grab and the whole operation is fraught with some danger.

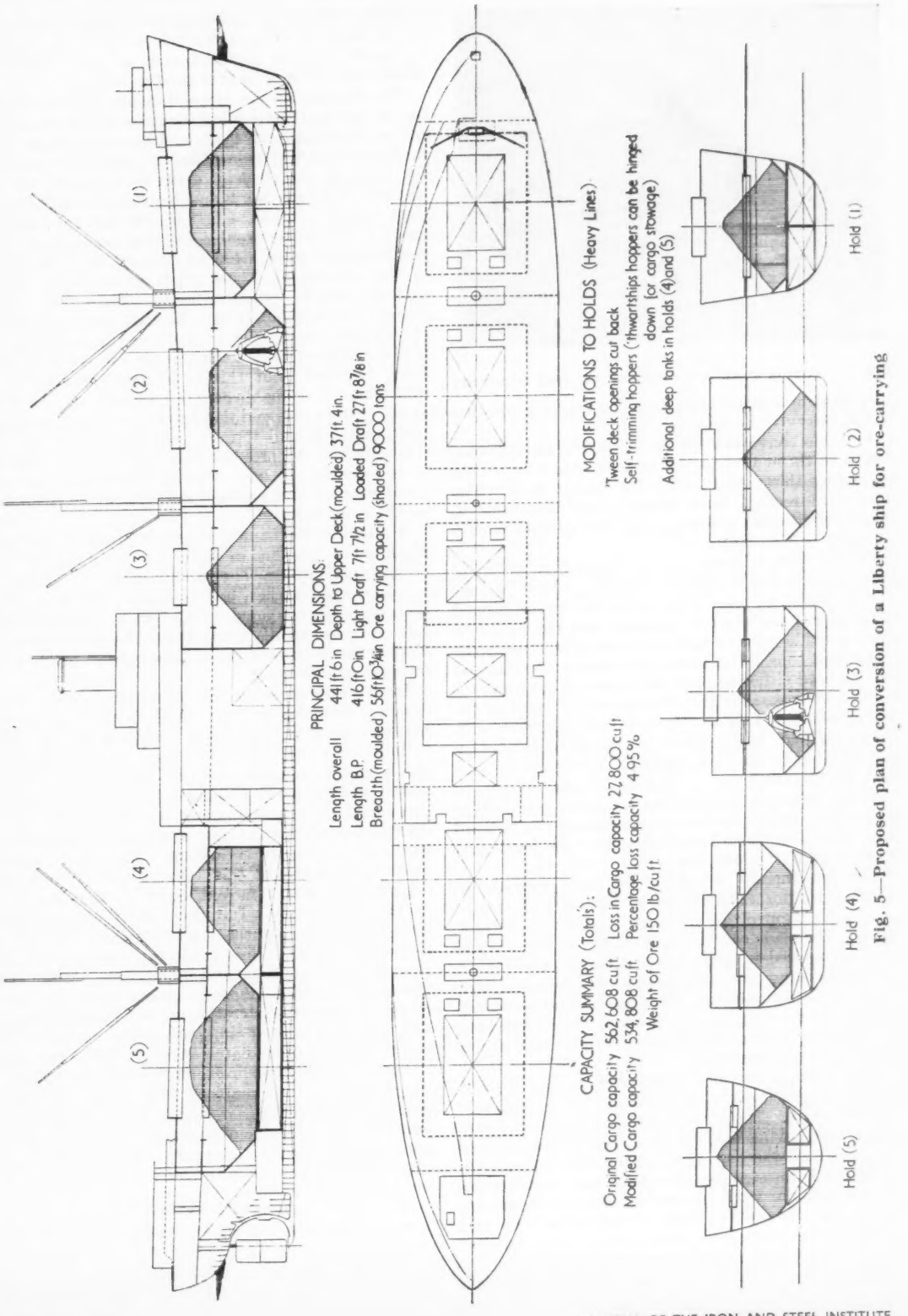
(1)
(2)
(3)
(4)
(5)
PRINCIPAL DIMENSIONS:
Length overall 441ft 6in Depth to Upper Deck (moulded) 37ft 4in.
Length B.P. 416ft 0in Light Draft 7ft 7½in Loaded Draft 27ft 8⅞in
Breadth (moulded) 56ft 10¾in Ore carrying capacity (shaded) 9000 tons
CAPACITY SUMMARY (Totals):
Original Cargo capacity 562,608 cu ft Loss in Cargo capacity 27,800 cu ft
Modified Cargo capacity 534,808 cu ft Percentage loss capacity 4·95%
Weight of Ore 150 lb/cu ft
MODIFICATIONS TO HOLDS (Heavy Lines):
'Tween deck openings cut back
Self-trimming hoppers ('thwartships hoppers can be hinged down for cargo stowage)
Additional deep tanks in holds (4) and (5)
Hold (1)
Hold (2)
Hold (3)
Hold (4)
Hold (5)

Fig. 5—Proposed plan of conversion of a Liberty ship for ore-carrying

Fig. 6—Aveling calfdozer modified for coal trimming

The plough is either too light for efficient working or too heavy to be man-handled.

Portable conveyors are used where a considerable length of throw is required, as for instance in a hold extending thirty feet under the bridge deck. The conveyors require hand feeding and also tend to interfere with the grabbing, and the method is only of value occasionally.

On the Great Lakes use is frequently made of specially adapted bulldozers, weighing about 7½ tons and of about 44 h.p. These machines are equipped with special tracks (one company uses old conveyor belting made up into pads) and are able to grip the steel tank tops. The blades are almost vertical and can be used either to push the material or to rake it out backwards. For the cleaning up of cargo in the Lake vessels, which are virtually self trimmers with very long holds, this method is excellent. One machine is estimated to do work normally requiring six men and double the time. "Lakers," however, are an entirely different proposition to ocean-going ships with their shorter holds and narrow spaces forward and aft. The bulldozer is also slow and inefficient when tackling a long throw.

For cleaning up in colliers we have modified an Aveling calfdozer by fitting a vertical wide blade, special blade-operating gear and bonded-rubber track shoes. The blade can be angled to 60° either side and this is required in order to shed damp material. A considerable amount of experimental work has been done with this machine, which has had many modifications tried out on it. The standard type of bulldozer is virtually useless for trimming work, due largely to its slow manœuvring.

The Aveling machine manœuvres rapidly through the use of selective clutch drive, and can be turned in its own length. The method of operation is as follows : the cranes having worked down to the tank top and taken out all the coal they can efficiently grab, the calfdozer is lowered into the hold, and, commencing at the outside, works round the hold in decreasing rectangles, using the blade to angledoze the coal towards the centre : when the coal is piled into the centre the grabs again start discharging, while the calfdozer carries on digging the coal out of the four corners. This small machine, still experimental, can do the work of 5–6 men, but it is not powerful enough to handle heavier material such as ore. Figure 6 shows this machine as it is used in colliers.

For cleaning up ore in ocean-going ships we make use of tracked mechanical navvies and back-acters of the Priestman cub type, and these machines each do the work of 8–10 men. They are especially valuable for working out of deep under-deck spaces, as, for instance, between No. 2 and No. 3 holds on "Fort" class vessels. It was at first feared that the exhaust gases would cause trouble in deep holds, and long flexible pipes were fitted to exhaust over the sides of the coamings. These pipes were always being broken, and in practice no ill effects have been experienced without them. Navvies and back-acters of this type can only be used where the height of the hold is sufficient to give them headroom, 18 to 20 feet being required ; but this is seldom found to be a difficulty. Reasonable care is necessary on the part of the drivers to avoid damage to the ship's framing, bulkheads, and tank tops, but again experience proves this to be less of a problem than had been anticipated. It is essential to have well-disciplined drivers and hatchwaymen and so avoid damage to the trimming machine by the grab.

A modified mechanical navvy is probably the best machine at present in sight for trimming ore in ocean-going vessels. The modifications to include a special-shaped bucket, body bumpers, spark arrester, silencer, rubber-bonded track shoes, upward-vision cab, and permanently fitted slings. Much development work remains to be done on this type of machine to increase its efficiency.

In the case of some new transporters now being designed special provision is being made for clearance between the legs, and extra height of lift, in order to hoist into and out of the ship, in light draught, the largest mechanical navvies which it is contemplated will be used. It must be remembered that these have to be taken out of the ship at the end of discharging when the bows, and consequently No. 1 hold, are frequently cocked-up. The navvy can be lifted by attaching it to the main hoist, from which the grab has been removed, or to an auxiliary hoist on the main bogey. In either case the main bogey must be able to span the track on which the navvy is stowed ashore. This track can also be used for changing grabs and general maintenance work. The trimming machine must be slung with its boom raised in order to enter the smaller hatch openings, and, to avoid wasted time, should be complete and ready to work immediately it is landed in the hold.

There are really two problems in trimming. Firstly, the digging out of material from deep under-deck spaces, for which the navvy offers the most promising solution. Secondly, the cleaning-up, one might almost say sweeping-up, of the open hold, for which the modified bulldozer offers the most promise.

Acknowledgments

The author wishes to thank the directors of William Cory and Son, Ltd., and of Rea, Ltd., for permission to give the information contained in the paper, and also to the various members of his staff for their help.

THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE SIXTH MEETING

The SIXTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 18th February, 1948. Mr. W. F. CARTWRIGHT (The Steel Company of Wales, Ltd., Port Talbot), Chairman of the Group, occupied the chair, and the President of the Institute (Dr. C. H. DESCH, F.R.S.) was also present.

The MORNING SESSION was devoted to the presentation and discussion of a paper on "Engineering Aspects of the Distribution and Utilization of Gaseous and Liquid Fuels in Iron and Steel Works," by J. B. R. BROOKE and J. S. BRYAN, and the AFTERNOON SESSION, following a buffet lunch at the Institute, to the presentation and discussion of a paper on "Soaking Pits," submitted by the Society of Furnace Builders. The proceedings of the AFTERNOON SESSION were published on pp. 415–424 of the August issue of the *Journal*.

PROCEEDINGS OF THE MORNING SESSION : 10.30 A.M. to 1.0 P.M.

Discussion on THE ENGINEERING ASPECTS OF THE DISTRIBUTION AND UTILIZATION OF GASEOUS FUELS IN IRON AND STEEL WORKS*

Mr. **J. B. R. Brooke** (Messrs. John Lysaght's Scunthorpe Works, Ltd.), in presenting the paper by himself and Mr. J. S. Bryan, said : When Mr. Headlam-Morley asked me to prepare this paper I felt that it would not be inappropriate to lay emphasis on the practical difficulties in an existing steelworks. We have had a large number of papers about new plants, but papers about existing plants and the problems which we have in our works at the present time should evoke a useful and practical discussion. At the same time this necessarily leads us to the problems which the plant manufacturers can help us to solve, and I hope that there are representatives of the plant manufacturers here today who will take part in the discussion and show us a way out of the difficulties which this paper outlines, and which some of us are in at the moment.

The other main feature of the paper is the description of the gas-distribution system at the Normanby Park works of Messrs. John Lysaght, Ltd. This gas-distribution system has been in existence for about two years and has proved to be of immense benefit. I will not say that it is unique, but it is at least something which can be looked upon as being part of the future equipment of most integrated plants which use various types of fuel.

Mr. **J. S. Bryan** (Messrs. John Lysaght's Scunthorpe Works, Ltd.), summarized the paper, and added, with reference to the section "Method of Control" (p. 120), that they were working on the system of co-operation between all departments and the control room. The other method was to have "push-button" control and simply inform the department concerned that their gas supply had been cut, but although this system is attractive—particularly under emergency conditions—it would lead to complications.

After reading the first paragraph under the heading "Coke Ovens" (p. 120), he said : Since this paper was written, we have had some dust deposition in the regenerators on the No. 1 battery after 16 years, but the trouble was not as serious as was at first thought, because we were able to drill through the checker walls and blow out the chambers. The dust seemed to accumulate about 5 ft. high on the valve side down to the partition wall. We have not as yet completed the cleaning operation, but the valve boxes on the cleaned chambers are back to the normal condition of alternating pressure and suction, instead of anything up to 12 mm. pressure ; we are therefore on the right lines.

Later, Mr. Bryan said : There seems to be a great discrepancy all over the country as to what is the best temperature at which to atomize liquid fuels. In South Wales they are operating, I understand, at a viscosity of about 250 sec. Redwood No. 1, whereas we run in the region of 150 sec. I have heard of other works operating with temperatures as high as the flash point, about 230° F. I think that the whole problem revolves round the fact that at each works it is necessary to find the conditions most suitable to the furnace and liquid-fuel plant, bearing in mind the essential factor that steady conditions must be provided in the furnace bath.

The **Chairman** : I have been able to see the control room which is mentioned in the paper, and I think that Mr. Bryan is very modest about it ; it is the most impressive fuel-control room that I have seen. It gives a bird's-eye picture of the fuel situation throughout the works, and almost, one might say, of the energy situation, and there is an excellent system of communications. Those of you who have had to struggle with an automatic telephone system will realize the benefit of direct lines to all departments on the Loudaphone system, as installed at these works.

Mr. **G. A. Young** (Messrs. Richard Thomas and Baldwins, Ltd., Ebbw Vale) : The authors have presented a valuable paper, and in reading it, which I did with great interest, I found myself mentally checking up the Lincolnshire plant with the plant at Ebbw Vale, and I was struck by the similarity of our development. A description of the Ebbw Vale plant, therefore, would add little to the information which the authors give regarding a modern plant, and my remarks will mainly cover some of our own experiences. It is invaluable to exchange experiences, because the information so obtained often throws new light on recurring problems.

On the question of gas cleaning, the type of plant to be installed will depend to a large extent on local conditions, but it is my view that it pays to clean blast-furnace gas to under 0·009 grains/cu.ft. Actually at Ebbw Vale we operate at about 0·004 grains/cu.ft., and seldom

* *Journal of The Iron and Steel Institute*, 1948, vol. 158, Jan., pp. 111–124.

reach a figure of 0·009. Our hot-blast stoves have been in operation continuously for over ten years with no trouble and are still giving excellent service ; furthermore, we have had no sludge trouble in our mains. About a year ago we had occasion to open one of our large mains to instal an orifice plate, and we found very little deposit in the main.

Large distribution mains are usually overhead, and of steel, with suitable expansion joints. If the expansion joints are of the bellows type, cleaning-out points should be provided so that the bellows can be kept clean ; otherwise they will become packed with dust.

Much time could be spent in discussing the various types of isolating valves which can be installed in a gas-distribution system. The authors have referred to the water seal, the dumpling valve, and the goggle valve. It is appreciated, of course, that what the authors have said on the subject of water seals is intended only as a general reference and that the typical water-seal arrangement shown in the paper (Fig. 2) is merely diagrammatic ; nevertheless when they say (page 114) that " It must be made clear that this type of valve is not used near the furnaces " I am wondering whether they have had some experience which has led them to make such a definite decision. They may have in mind the saving in time by operating a goggle valve instead of a water seal, but against this the water seal has the advantage, as the authors themselves have said, of requiring no mechanical maintenance. I feel that this is a most important consideration, because goggle valves at blast-furnaces have to operate under exceptional conditions ; they are usually situated in exposed positions, they are subject to dust and moisture, and they are brought into service only infrequently.

We have water seals installed at the blast-furnaces at Ebbw Vale and have experienced no exceptional operational difficulties in ten years. We have also installed water seals at other points on the plant, for example, at the slab reheating furnaces, where men are required to carry out week-end work to furnace hearths, brickwork, etc. In course of time the ordinary gas shut-off valve at a gas-consuming point becomes coated with a layer of dust which may prevent it from closing properly, and we have come to the conclusion that a water seal in addition to the shut-off valve is an effective arrangement to safeguard the men from possible gas leaks.

Another place where we have provided water seals is on the gas-main branches to each boiler on our high-pressure boilers. These seals are additional to the main gas valves, and they safeguard the men who have on occasions to work in the boilers, as well as facilitating the maintenance of the gas shut-off valves at each boiler. We also have a water seal on the blast-furnace-gas supply main to the coke ovens.

With regard to the operation of the water seal, the authors have made the point that during operation a continual flow of water is maintained and that it is imperative that a constant watch be kept on the overflow pipe to ensure that the water is continually flowing. It is equally important that when the water seal has been filled the supply of water entering the seal should not be greater than the overflow can take. It is a good arrangement for the ordinary water seal with the single overflow pipe, such as we have at the slab reheating furnaces and the boiler plant, to have the overflow pipe larger than the water-supply pipe. The authors' diagram (Fig. 2) gives the impression that the water-supply pipe shown is larger than the overflow. At Ebbw Vale it is our practice to turn the water supply down to only a trickle once the water seal has been filled.

On the question of keeping a constant watch on the overflow, it should be made easy to observe. I have known a water seal to be located outside a building and 25 to 30 ft. above ground level, making it necessary to climb on to a platform to observe the overflow.

At Ebbw Vale we have installed the spectacle type of valve with a mechanical clamping device for the gas-cleaning plant and for the main gas-distribution system, and in the early days of operation we had our share of trouble. As we have now reached a stage when the valves give the minimum of trouble, it may be of interest to mention what our experience has been. Originally the valve plate had a copper seating, and in time the copper became hard, making it increasingly difficult to maintain a gas-tight fit. As a consequence of the difficulty in shutting off gas leaks, it was natural for the operator to apply more and more pressure through the clamping device, so that in addition to the copper seating becoming harder it was cut into and grooved, making it still more difficult to obtain a gas-tight fit. In the end, gas leaks became so bad that ordinary maintenance of the valve, including the lubrication of the cams, was neglected, and by over-straining the clamping gear became distorted. There was only one outcome to the sequence of events which I have described, namely to have a shut-down and a complete overhaul.

On the recommendation of the suppliers of the valve, we adopted a soft seating of asbestos and graphite with excellent results. Only just sufficent pressure to seal off gas leaks need be applied, and when the valve is in the open position the seatings are regularly graphited to keep them soft. There should be a gas-tight fit at all times to ensure proper maintenance of the valve, and it is fundamental that the clamping unit should be in true alignment, with all the cams working freely. Because gas valves of this type are often exposed to extreme weather conditions and are affected by water and steam, it might be an advantage to have the bushings and gears of the clamping arrangement made of a non-metallic material. There are plenty of materials of that nature on the market which are quite suitable.

When two or more gas mains are joined to a mixed gas line—as, for example, with coke-oven and blast-furnace gas—the isolating valves should be on each of the branches and not in the mixed line.

For ease in inspecting orifice plates it is an advantage to have them located between the isolating valve and the consuming point. Orifice plates should be provided with a drainage hole at the bottom of the plate, and the drains on either side of the orifice plate should not be joined to a single line going to the seal pot but should be connected to the seal pot separately. Impulse lines should be sited so that they drain back to the main or to a special drainage point.

Gas-holders are essential to ensure uniform pressure throughout the system and to provide a working margin sufficient to take care of fluctuation in the make and in the consumption under normal conditions. I am also in agreement with the authors that a central gas control is necessary to control the distribution of the large volume of gas and to ensure that the gas is being used to the best advantage.

The authors say that the paper is intended to be complementary to contributions which it is hoped that representatives of plant manufacturers will make. Such questions, therefore, as the design and efficiency of furnace burners, the design and construction of differential devices for metering, automatic-control arrangements, and so on are likely to be dealt with in the future. With regard to instruments generally, they should be of robust construction and easy to maintain. They should be

located in positions which will give them a fair chance to operate satisfactorily; for example, they should not be too close to heat, and from the point of view of regular maintenance and adjustment it will pay to give the mechanic plenty of room in which to work. The proper functioning of instruments can also be interfered with because of excessive vibration due to the panels being fixed to platforms which are attached to steel structures on which cranes are operating. A good method is to have panels mounted on independent supports, not connected to any other steel structure. Excessive vibration can, of course, be damped by rubber pads or springs.

As an aid to maintenance, at Ebbw Vale we have adopted a system of plug-in fittings to units of electrical transmitting meters, so that an apprentice can be sent to change a unit without having to disconnect four or more wires. This avoids the risk of having units wrongly connected.

The attitude of the operators to instrumentation is often, to start with, somewhat suspicious, instruments to the operator being new gadgets in which he has little faith. It is of the utmost importance, therefore, that by giving reliable service his goodwill and confidence in the instruments should be obtained. Moreover, the maximum reliability is essential in order that accurate data can be compiled and efficient standards arrived at.

Mr. **J. S. Bryan**: Mr. Young mentions a cleaning plant cleaning down to 0·009 grains/cu.ft. The specification for our new Lodge-Cottrell plant is 0·007 grains/cu.ft., and it is expected to come down to 0·004, so that we are more or less the same.

We do not instal water seals anywhere near the furnace. We have at the moment isolating valves of the dumpling type, and are installing goggle valves between the dust-catchers and the common main on the crude-gas system before the cleaning plant. After the cleaning plant we shall have water seals. I do not know how near to the furnaces Mr. Young instals water seals.

Mr. **G. A. Young**: Our water seals are installed between the dustcatchers and the crude-gas main.

Mr. **J. S. Bryan**: We are of the opinion that, owing to the quantity of dust likely to be deposited, due to furnace conditions, and the blowing of seals, we would rather instal goggle valves, as giving more positive action.

Mr. **G. A. Young**: I ought to tell you that our seals are 16 ft.

Mr. **J. S. Bryan**: That makes a vast difference.

Mr. **G. A. Young**: We take every precaution to make sure that we have something big enough to stand up to any pressures that we are likely to get.

Mr. **J. S. Bryan**: That provides the answer, but the comparison of costs in that case does not really apply. We made a comparison between this valve and the goggle valve which was in the water seal's favour, but a valve 16 ft. high is a colossal structure.

Mr. **G. A. Young**: That is the depth of the seal.

Mr. **J. S. Bryan**: With regard to goggle valves, I am grateful to Mr. Young for his remarks about the seating, which we shall note very carefully, because we have only had one installed, for about six months, and all our other furnaces are to be equipped with them. We agree with all his other remarks.

Mr. **D. C. Hendry** (Messrs. Stewarts and Lloyds, Ltd., Corby): I am against using water seals of any kind whatever. We have had experience of them in dirty-gas mains and in clean-gas mains, and are steadily replacing them throughout the works. This is less easy on the clean-gas system and perhaps less necessary, but where we instal new clean-gas mains it is our intention to adopt the spectacle type of valve. mechanically clamped. We have quite a number in operation on our dirty-gas-main system which are thermally operated, and we have had very little trouble with them on gas which is probably as dirty as any produced in this country. I think that anyone who goes over to that type of valve is more likely to be free from trouble than he would be with water seals.

Water seals, in my experience, have been the cause of some very dangerous situations. At the furnaces we took the precaution of adding, to the water seals, a goggle plate, and having done that we felt that we had better be rid of water seals altogether and go in for proper spectacle valves. The water seals at Corby, although they were quite as deep, I believe, as those at Ebbw Vale, were not free from various troubles due to plugging, and on more than one occasion we have had to use the services of explosives experts in order to break the internal deposits free while the system was alive. We do not like doing that, and troubles of this sort tend to alter one's point of view.

Other troubles associated with water seals arise in connection with the weather. We have seen water seals freeze and overflow pipes freeze and valves crack, and that has given rise to difficulties. As a result we have decided to depart from the more or less conventional type of water seal and get on to something newer and less likely to cause trouble.

Mr. **E. W. Plumley** (The Steel Company of Wales (Lysaght Works), Ltd., Newport): I should like to ask a question in connection with the design of the new electrostatic plant. It is stated in the paper that it is highly desirable to keep the length of the hot-gas main as short as possible. Is it practicable to arrange in this particular works for the dustcatcher, the washer, and the electrostatic precipitator to be in the same vertical axis close up to the blast-furnaces, with one cleaning plant to each blast-furnace?

On the question of the distribution of the fuel oil, it is stated in the paper that the temperature drop through the system is 3° C. It does not appear from the diagram that any precaution has been taken in the new circumstances to take care of that small temperature drop. In other words, it is stated in the paper that the storage tanks should be maintained at a lower temperature in future; in fact, the temperature of 100° F. is mentioned. If the temperature drop round the system is only 3° C., should there not be an extra vessel interposed in front of the pumps, between the storage vessels and the pumps, with automatic temperature control on that vessel, so that the hot oil on the return system does not return to the storage vessel proper?

Mr. **J. B. R. Brooke**: On the first point raised by Mr. Plumley, we have not sufficient room to do what he refers to, but that would be ideal in our opinion.

Mr. **J. S. Bryan**: With regard to the second point, I said that we would connect the return-oil main into either the storage tank or the pump suction. It is more than likely that we shall connect it into the transfer-pump suction itself, so as to keep a closed circuit, and just draw from the storage tanks for the make-up.

Mr. **E. W. Plumley**: The picture that I have in mind is of a tank thermostatically controlled, possibly of four or five truck-loads' capacity, and the return oil coming back to it.

Mr. **J. S. Bryan**: Yes, I agree that that would be one method of overcoming heat loss, but the problem of pumping high-temperature oil still arises, and one would have to be careful that the oil mixture is not at too high a temperature, in order to avoid cavitation in the pump.

Mr. **F. B. George** (Consett Iron Co., Ltd., Consett): As Mr. Young has said, there is a great similarity between the systems in various works, and the principles are

very much the same. However, I propose to mention some of the differences in our own plant at Consett as compared with the plant described by the authors.

In considering the question of gas cleaning, we are in a very similar position to that of the authors, as we are changing over from a Thiesen plant to an electrostatic plant. The putting of the gas-cleaning plant next to the blast-furnace, which was referred to earlier in the discussion, is a normal practice in the United States. We were very much impressed by the arrangement, and were anxious to incorporate something of the same kind in our own plant. It was rather difficult to do so, owing to one new furnace having just been built and another being about to be built, and when we spoke to the experts about it they were not happy about the size of plant to deal with a blast-furnace of only 20 ft. hearth diameter. That may have been wrong, but their opinion made us go in for an independent electrostatic plant. We did, however, try to compromise and tried to get rid of the long crude-gas main by putting the pre-coolers next to the dustcatchers.

The plant is not in operation yet, and so we cannot say how this arrangement will turn out, but the idea is that there will be a semi-clean gas main flushed into a hydraulic flume which will deliver into the dustcatchers ; the treaters themselves will be at one end of the plant. I do not know whether anyone has any ideas or views to express on this, but we felt that it was a reasonable compromise.

There has been a good deal of discussion of water seals. One can only speak of them as one finds them. Apparently at Corby they have had unfortunate experiences with water seals. We have had some unfortunate experiences owing to very severe weather (we are in an exposed position), but on the whole we have found these units to be useful. We are using goggle valves on the outlet from the dustcatcher to the crude-gas main, but we have water seals for the whole of the clean-gas system, partly for the reason that Mr. Young has mentioned, namely, to obviate the danger of men working in or near mains when the system is alive and they have to deal with individual furnaces. We have, however, two types of water seal. Firstly, we have the water seal as a shut-off valve, which is a complete **U**-valve with two separate legs, so that there is no question of leakage from one side of the baffle to the other. We always provide these with a large overhead tank of sufficient capacity to fill the seal instantaneously, so that we get positive and quick shut-off.

Secondly, we have, not only on the clean blast-furnace gas mains but also on the coke-oven-gas mains, water-seal explosion valves. These are self-regenerative and also full bore, so that if there is an explosion the seal is blown immediately and there is a complete vent to atmosphere of the full diameter of the main, while as soon as the explosion has been dissipated the seal regenerates itself by refilling. So far we have not had any explosions, so that we cannot say whether these seals are as effective as we hope that they will be ; but we have placed them all over our system. The fact that we have had no explosions may be due to the care which we have always taken in purging and so on, but we still feel that these seals are a very necessary safeguard.

As regards the question of gas control and distribution, we have had a gas-control department since 1926, when we first put in our high-temperature coke ovens and started to use coke-oven gas in the works. I do not know how we should have operated the plant during and since the war without such a system. We have, over the last 25 years, managed to get a reasonable amount of co-operation between the different production departments and the gas-control department, but we give the gas-control department the overriding authority finally to say what is to be done with regard to fuel.

We have in the gas-control department remote indications of the contents of the coke-oven and blast-furnace gas-holders, and that is all right until the electricity fails, when, of course, it is no use at all. It is obvious that the more integrated a plant becomes the worse the troubles are likely to be when something really goes wrong ; the biggest difficulty, at least in our experience, is a complete failure of the electricity supply. You may have all kinds of safeguards, but the time does come sometimes when you have a complete failure of supply. We had one very devastating experience during the war, when a barrage-balloon cable fouled the main transmission line and we found ourselves apparently sustaining the whole load of the grid in the North of England—at least, that is what it seemed like to us—with the result that we got into a complete mess. Our breakers all went out. We could not get the blowers going because we had no current for the pumps ; we could get no blast-furnace gas because no blowers were going ; we had no steam, because we had no blast-furnace gas. You can imagine the difficulties.

We are now in process of centralizing the whole of our power generation (retaining the connection with the grid), our blowing requirements, and any steam requirements for the rest of the works in one central power station, and we hope that that will be some safeguard. It will probably not be an absolute safeguard ; it is not possible to have an absolute safeguard against a complete power failure, which probably arises from outside your plant, so that you lose your own supply owing to some trouble external to your plant. As long as you have that connection you have to face that difficulty. We are contemplating transferring the control of fuel and power to the central power station, not taking it out of the hands of the fuel department but transferring the physical control room to that point.

We have in our gas-control department at the present time a manually operated telephone exchange, and we find that that is an advantage. We are proposing to maintain the manually operated telephone exchange in the central power station, but to incorporate with it the general office exchange as well, so that the whole of the telephone exchange is in one place, instead of in two as at present. We find that the advantage of the manual exchange in fuel and gas control, and in general works control, is that in an emergency the operator can interrupt people who are talking about filling up their football-pool coupons, or something of that kind ; he can interrupt the non-essential conversations in favour of those that are essential. We have found that of the greatest value both during the war and during our normal operations. The only doubt that we have in our minds is with regard to the question of the remote indication of the contents of the gas-holders. When our remote-control indication failed with the complete failure of the electricity we could use a runner from the gas-holders to the gas control, which was only about 100 yards ; but with our central power station we should need a real " three-miler " to be any use as a runner. There is therefore that doubt in our minds, which someone here may be able to resolve, as to whether it is wise to take the control away from some place close to the gas-holders to a place more distant.

I should like to indicate the difference between opinions in one place and in another by referring to the fuel burners on the open-hearth furnaces. We are not yet using coke-oven gas on the open-hearth furnaces in any quantity, because the extensions to our coke-oven plant are only just coming into operation, but we have

thought of separating the burners; in other words, having the fuel-oil burner or liquid-fuel burner as an independent burner on top of the coke-oven-gas burner, the idea being that we could control the direction and the position in the furnace of the two independently. We feel that that may be of some advantage.

I have tried to show the different opinions that arise. It is obvious that in dealing with any problem in a works already in being it is necessary to have regard to the different conditions. We have heard today that at Corby they have had difficulty with water seals, and we have found a similar difficulty; if anyone can give us any views we shall be most grateful, because some of our plans are rather different from what has apparently been proposed elsewhere, and we may be quite wrong in what we are considering.

Mr. **J. S. Bryan**: With regard to the gas-holder indicator, we have that on a separate system, with accumulators for emergency conditions, so that even if the power fails we still have the indicators showing.

Mr. **F. B. George**: I wonder whether an accumulator system would be satisfactory for so long a distance?

Mr. **J. S. Bryan**: Our coke-oven gas-holder is about 500 yards away, and we still have that on a separate system. The blast-furnace gas-holder is only 20 yards away. The control-room Loudaphone is completely separate. No one can ring up any other department direct; they must come through the control room.

Mr. **F. B. George**: We have a Loudaphone system as well, in fact I think that we have three systems, but we found that the G.P.O. system seemed to be more reliable than any of the others.

Mr. **J. S. Bryan**: We have not had any trouble with the Loudaphone system. We have the ordinary interworks system for other information.

With regard to the centralization of the power generation, we intend to unify the control of the boilers and generation in one power station, but the final control will still be retained by the fuel-control centre, which will be equipped with additional instrumentation. At the present time the fuel controller does vary the works generation in accordance with the gas available, by verbal contact with the switchboard attendant.

Mr. **F. A. Gray** (United Steel Companies, Ltd., Rotherham): The authors mention that they are using a 50/50 mixture of pitch-creosote to prevent settling-out of the solids. Have they used or considered using higher ratios, such as 70/30? It would appear that a higher pitch content would improve the luminosity and heat transmission of the flame. It would also make the creosote-oil supply go a little further.

The distribution system described in the paper appears to refer to fuel oil. Is the same system applied to pitch-creosote, and are the furnaces using pitch-creosote and coke-oven gas, fired in the same way as those with fuel oil and coke-oven gas?

It is stated in the paper that the checker openings have been enlarged on the furnace which has been converted to liquid-fuel and coke-oven-gas firing. Has this change been made in the expectation of greater checker deposits? We will shortly be firing two furnaces with a 70% pitch/30% creosote mixture, and we have heard reports that there is a good deal more checker deposit with pitch-creosote mixtures than with fuel oil. I shall be obliged if the authors will say what their experience has been.

On the question of meters, the authors say that they are using orifice meters to measure the flow of petroleum oil. Are they also using the same method for measuring pitch-creosote?

In connection with metering, I would like to add that we measure the rate of flow of steam and oil to our furnaces. Steam measurement is found to be valuable not only in enabling us to control the character of the flame but also from the point of view of steam economy. We find that after a comparatively short time wear of the steam-control valves can give rise to a very high steam consumption on the idle burner. For example, when we installed a steam meter on one of our furnaces we discovered that the steam consumption on the idle burner was 500 lb./hr., compared with 900 lb./hr. used for atomization. Without steam measurement such losses escape unnoticed.

I notice that in their new burner design the authors use tip atomization, I am very interested in this, because it seems wrong to atomize at the back and then push the atomized fuel down a long tube, which probably destroys a good deal of the atomization. On the other hand, with tip atomization there is the difficulty of carbonization and blocking of the nozzle. I should like to know whether the authors have tried this design, and, if so, with what result.

Mr. **J. S. Bryan**: With regard to the burning of creosote-pitch, we do use coke-oven gas as well, mixing in the ratio of 50/50, based on heat input, the same as with fuel oil. It is our present practice, particularly in the winter, to run with a mixture of 55% creosote and 45% pitch. I did not gather whether Mr. Gray was proposing to run with 70% creosote or 70% pitch.

Mr. **F. A. Gray**: With 70% pitch, 30% creosote.

Mr. **J. S. Bryan**: We find that the 50/50 mixture is about as low as it is possible to go with the creosote if there is not to be trouble in the mains and in the tanks.

Mr. **F. A. Gray**: We are using steam-jacketed pipes, and the whole system is being laid out so that if necessary we can use pitch.

Mr. **J. S. Bryan**: If we go to even 55% pitch we run into a great deal of trouble; we have fluctuations of pressure all the time. That may be due to the fact that our system is not designed to cope with 55% pitch. With more steam heating on the mains you may get away with it, but we think that 55% creosote/45% pitch is correct in our case.

Mr. **F. A. Gray**: We are going to heat it up to about 300° F., and as the 70/30 mixture is equal to a coal-tar-fuel value of 300, we shall, by raising it to that temperature, have the same viscosity as you have on the 50/50 mixture.

Mr. **J. S. Bryan**: What will the atomization viscosity be?

Mr. **F. A. Gray**: The atomization viscosity will be 100 Redwood No. 1.

Mr. **J. S. Bryan**: That is equivalent to a kinematic viscosity of 0·25 Stokes, and the Association of Coal Tar Distillers specify 0·25 Stokes for atomization.

Mr. **F. A. Gray**: On fuel oil we heat to the flash point, or actually beyond it.

Mr. **J. S. Bryan**: We have a certain amount of deposit in the checkers from creosote-pitch, but it has not been excessive.

Mr. **F. A. Gray**: Could you say how much shorter life you get on the checkers?

Mr. **J. S. Bryan**: I cannot say off-hand, but it has not been noticeable.

Mr **J. S. Bryan**: I do not know what troubles you may have when burning pitch to the extent that you suggest. We use orifice meters for creosote-pitch as well as for fuel oil.

We have used the new design of burner which I showed, with front atomization, on fuel oil at one of our furnaces, and we have had exceptionally good results with it. That is with the external slag-wool insulation to the steam tube. No carbonizing at all has been experienced. Owing to the amount of coke-oven gas available,

we have had to convert to mixed firing and the back-atomization-type burner is used both for fuel-oil/coke-oven-gas and creosote-pitch/coke-oven-gas firing. The tip-atomization burner has not been used for creosote-pitch.

Mr. **L. H. W. Savage** : (British Iron and Steel Research Association) : I should like to know whether the authors have any particular trouble in metering their crude-furnace gas. I am interested in where they locate their orifice plates and how they keep them clean, and what fluctuations they get owing to the normal operation of the furnace.

The next point is possibly outside the bounds of the paper, but I am wondering whether the authors propose to extend their central control to steam and electric power. I am not very familiar with their works, but I believe that they generate most of their current by gas engines ; I do not know whether they have turbo-generators as well. Some indication of the steam obtained from fuel-fired boilers and waste-heat boilers, respectively, is also of particular interest in the allocation of the fuels. Going a stage further, they probably use imported coke as well as coke made in their own coke ovens, and some indication of the hourly rates of these other direct fuels and the indirect fuels would increase the value of the paper.

Mr. **J. S. Bryan** : On the existing plant we do not meter the crude blast-furnace gas ; it is the semi-clean gas that we meter, On the new plant we shall be metering crude blast-furnace gas. The length of main that we have available is very short, and the manufacturers intend to make models of one section to calibrate the meter. They do not consider that we should fit any special cleaning device for the orifice plate, but I feel certain that we shall have to fit steam, or some other means of clearing the dust away from the orifice plate.

We are now considering bringing the major items of steam allocation into the control room, but we have not yet worked out the complete plans, so that I cannot give any further information on that point.

With regard to the information required concerning steam makes and additional fuels, this creates a subject for a complete paper, together with heat-distribution diagrams, etc., and is outside the bounds of the paper under discussion. However, I can briefly answer certain points that Mr. Savage made.

We generate approximately 75% of our electrical demand by turbo-alternators, the balance being imported from the grid. The average works demand is approximately 6200 kW. The only gas-engine generator is a 500-kW., D.C. set which is used only for emergency conditions. The turbo-alternator sets take steam at 150 lb., and 480° F., and steam from the mill engines at 12 lb./sq.in. The consumption on high-pressure steam is 16·75 lb./kWh., and on low-pressure steam, 33 lb./kWh.

The main boiler plant operates under the conditions detailed in the paper and consumes 17·1 cu.ft. of blast-furnace gas per pound of steam.

The waste-heat boilers produce steam at 160 lb./sq.in., and 420° F., and the make is equivalent to a credit of approximately 1,500,000 B.Th.U. per ton of ingot make.

Mr. **R. Whitfield** (The Incandescent Heat Co. Ltd., Birmingham) : The authors' use of grammes per cubic metre puzzled me at first, because the average engineer is used to thinking in terms of grains per 100 cu.ft. when dealing with dust and so on. However, if the figure in grammes per cubic metre is multiplied by 43·8 (say 44) we obtain the figure in grains per 100 cu.ft.

The training of the company's own personnel is, I find, of immense advantage, not only to the men concerned but to the company. When installing innovations, and training personnel to handle them, it is most important to explain to the men the reason for the innovation. This tends to remove any lurking suspicion of them that the men may have, and obtains their co-operation.

An important question is whether there is any advantage in atomizing oil by pressure air instead of steam. The answer often given is that steam is available, but that is not a very satisfactory reply. In considering which is better I am not thinking merely of the economics of the matter. In the case of many melting furnaces and other furnaces which I have inspected, it is found that wet rather than dry steam arrives at the burners, and, since the latent heat of steam is of the order of 1,150 B.Th.U./lb., it is obvious that some useful heat must be absorbed in re-evaporating the steam. Approximately the same amount of heat is absorbed by heating the atomizing air to the same temperature as the steam at the burner. It is important to realize that air contributes towards the combustion, whereas steam does not. There is apparently no reaction, and in any case a great deal depends on temperatures, concentrations, and partial pressures.

It is interesting to compare the percentage of products of combustion and therefore their partial pressures, which are influential. Figures based on an oil composition of 86·1% of carbon and 13·9% of hydrogen, and 10% additional air, the calculated air consumption being 190 cu. ft./lb. of oil, are as follows :

	Atomizing by Air, %	Atomizing by Steam, %
CO_2	12·1	11·1
H_2O	11·7	19·3
N_2	66·7	61·0
Air (excess), 10%	9·5	8·6

These are interesting figures, apart from economics, because carbon dioxide and nitrogen are powerful decarburizers in the presence of superheated steam. For low-carbon steels decarburization may be unimportant, but it is very different with high-carbon steels. I am referring here to heat-treating such as forging and so on, and not to steel melting, with which I am not competent to deal.

It is possible with efficient control to have a moderately reducing atmosphere with oil firing ; in this case the reactions between the gases can be very complicated, and the metallurgical reactions are far-reaching, influencing oxidation, reduction, and/or decarburization. The introduction of steam reduces the flame temperature, thus lowering the radiation factor in proportion to the fourth power of the absolute temperature. Taking a normal flame temperature of 2400° C., if this is reduced to 2300° C. the reduction in radiation is from 32 to 27, which is considerable for such a comparatively small drop in flame temperature. Atomizing by air would not cause such a drop.

In view of the extension of oil firing, such a problem is worth pursuing. Economics does not provide a competent answer, because other factors may be of greater importance. I know one works where they are delivering oil to their steel-melting furnaces at approximately 80–90° F. above the flashpoint of the oil. I do not know whether that is running any risk or not, but it does not seem to me to be wise.

Mr. **J. B. R. Brooke** : I should like to thank Mr. Whitfield for raising the question of the use of air or steam for atomization. I think that the main reason why we are using steam is that steam is available, but there does seem to be something in the point which he has raised. I do not know whether anybody here has expert knowledge of the value of using the one or the other, but I think that the point is of great interest.

Mr. **F. A. Gray** : We are not running as high as 80–90° F. above the flashpoint, but we are operating at one plant at up to 10–20° F. above it. I do not consider that there is any danger, as the oil at this temperature is not exposed to the air. The heating of the oil is done in a similar manner to that described by the authors, namely, by passing it through the heaters and the circulating system to the burner. Oil not burnt is returned to the inlet side of the pump. The oil in the storage tank is maintained at a temperature of about 90° F., *i.e.*, well below the flashpoint. The trouble that might occur with high oil temperatures is that vapour formation might result in it not being possible to pump the oil properly and so give a fluctuating flame in the furnace.

Mr. **F. B. George** : We have used air for atomization. We considered using all sorts of things, including coke-oven gas and blast-furnace gas, and steam. We started off with low-pressure air and comparatively low-pressure fuel. I think that we shall have another attempt later, but the trouble that we found was that we could not get the flame velocity and direction that we wanted, and we very easily burnt out the furnace roof without making very much impression on the charge. That, however, may have been a question not of the air but of the pressures that we were using. We were not able at the time to increase the pressures, and so we went over to steam, and found that we obtained good results with steam. I believe that on the producer-gas furnace the amount of steam in the fuel is higher than in the case of the liquid-fuel-fired furnace. I think, however, that it is worth while having another attempt to use air. It will probably be a matter of the design of the burners, the relative pressures of fuel and air, and so on. We have not abandoned the idea of trying air again at some later date, when we have a little more experience, at some more suitable pressure.

Mr. **A. L. Cude** (British Iron and Steel Research Association) : I have recently been collecting a good deal of information about oil burning, but I have not much information on the subject of air atomizing. Theoretically, it would certainly appear to be much better than steam, simply because a large quantity of diluent gas is eliminated from the flame. I have, however, heard of one reheating furnace which changed over from steam to air atomizing and obtained a very considerable reduction in the fuel consumption.

There is one question which I should like to ask the authors. I notice in the paper that they use steam and oil pressures of the order of 30 lb./sq.in. In all the works that I visited I found pressures ranging from about 80 up to 150 lb./sq.in., and I wonder whether the authors have ever used, or considered using, higher pressures, and whether in their opinion these are at all necessary.

Mr. **J. S. Bryan** : We run, as you say, at about 30 lb./sq. in. pressure, and we do not consider that we need to go any higher than that. We have tried going higher, but we do not get any better results. There seems to be a great divergence of opinion on oil firing, and you have to find the conditions most suitable to your own plant, but we consider that a pressure of 30 lb./sq.in. does give a satisfactory flame.

Mr. **J. T. Davies** (The Steel Company of Wales, Ltd., Port Talbot) : The authors have already dealt with the question of dirty blast-furnace-gas metering, in which I was particularly interested, but I would be glad if they would tell us what the blast-furnace-gas production works out at per ton of coke consumed by the blast furnaces, and also how the total of dirty gas produced and metered balances up with the total blast-furnace gas distributed.

With regard to the M.A.N. blast-furnace gas-holder, is there any serious fouling of the sealant by the dust which is carried into the gas-holder with the gas ?

In respect of water seals on gas mains, it would appear that the chief objections to them are (*a*) the danger of water displacement by explosion and (*b*) trouble due to serious frost or freezing of the water, and damage consequent upon the following thaw. I think these troubles can usually be taken care of by the method already mentioned in this discussion, *i.e.*, by ensuring adequate water circulation and overflow—and by suitable lagging of valves and pipes where necessary, and by the provision of light manually operated butterfly valves in the gas main on either side of the water seal to prevent blast following upon an explosion displacing the water. This type of valve is easily operated and is simply locked in a fully open or closed position, as required, by one labourer type of operator. On the other hand an isolating valve of the goggle type not only requires trained maintenance but usually needs a number of operatives to get it to function.

With regard to the effect of dust on coke-oven regenerators I would like to know the effect which the dust accumulation in the regenerators had relative to the heat consumption per pound of coal carbonized.

Mr. **J. S. Bryan** : The blast-furnace gas is metered in a semi-cleaned state, and the quantity varies between 145,000 and 150,000 cu.ft. per ton of coke.

With regard to the fouling of the sealant of the M.A.N. type blast-furnace gas-holder, we have not experienced any serious fouling, but this is entirely due to careful servicing on the lines detailed in the paper.

The dust accumulation in the coke-oven regenerators did increase the heat consumption per pound of coal carbonized, by approximately 100 B.Th.U.

Mr. **J. H. Butler** (Stanton Ironworks Co., Ltd., near Nottingham) : On the question of individual superimposed precipitators at the blast-furnaces, there are two points which might be borne in mind. I think I am right in saying that one of the main arguments put forward by the Americans in favour of these components is the comparatively limited amount of room that they take up. That may be so when considered on new plant layout, but so far as applying them to an existing plant is concerned, there is usually such a collection of ancillaries around the furnaces that it is often more difficult to get the individual units in than to put down a central plant a short distance away.

I was interested in Mr. George's remarks on that point, because I was with him at the time that the plant in question was under consideration, and the previous remarks applied there. We asked our American friends over and very seriously considered individual units, but we could not get these in, bearing in mind the existing boilers, etc.

Another consideration is that a fouled or cracked insulator on an individual unit will mean that furnace bleeding to atmosphere, unless the units can be suitably interconnected, whereas a modern centralized plant can usually take sufficient overload for a limited time to enable this situation to be dealt with satisfactorily.

Mr. **R. Andrew** (Messrs. John Miles and Partners (London), Ltd., London) : I should like to ask the authors what is the practical use of measuring the crude gas before the gas-cleaning plant, and whether it is their intention to line the crude-gas main to avoid any danger of reaching the dew point of the gas before it reaches the gas cleaners.

Mr. **J. S. Bryan** : With regard to the metering of the blast-furnace gas, our blast-furnace manager, when asked whether he would like that included, said that he preferred to have it because it gave him a good guide as

to the actual working of his furnace. With the normal fluctuations which occur there is always a reason for them, and he liked to see the chart and say that so-and-so was happening. That was his main point. Each furnace is separately metered, and then we shall meter the total make after the cleaning plant.

The crude-gas mains will be lined from the top of the furnace down to the dustcatchers, but not from the dustcatchers through to the gas-cleaning plant.

Mr. **A. C. Jennings** (Sheffield and District Gas Co.) : We are not concerned, of course, with dust in the mains and so on, but I have found this paper and the discussion very interesting. The authors mention that a gang is kept continually at work dealing with dust in the gas mains. Is that done while the mains are under pressure ? If so, it would be interesting to know how it is done.

My other question is in connection with the authors' control room. We have had a control room for some time, and from it we control gas over an area of 560 sq.miles from one point. One of the factors which had a big influence on the operation of the control room is to be able to forecast what the load is going to be on any particular district at any time. We are generally able to forecast it fairly accurately even over holiday periods several weeks in advance. Certain temperatures and atmospheric conditions have to be taken into account, but we set ourselves a plan to work to well beforehand. I should like to know whether that is the method of operation at Messrs. Lysaghts.

Mr. **J. S. Bryan** : We do clean mains when they are under pressure. We have holes along the top of the semi-clean gas main, through which the cleaning gang insert long pressure-water rods and flush out. There are small draining points along the bottom of the main. The cleaning gang go systematically through the system.

With regard to the allocation of fuels and changes in allocation, a complete balance sheet is made out for the plant ; we know what the gas make from the blast-furnaces should be, and the actual make from the coke ovens, and we work out the distribution to cover all the plant requirements and arrive at a balance. If there is any modification owing to a blast-furnace going off, we have to take action to neutralize the deficiency.

Mr. **A. C. Jennings** : But, generally speaking, from day to day it is the same ?

Mr. **J. S. Bryan** : Yes. We make out a plan for the actual plant conditions, and that is constant. We fluctuate round that.

Mr. **A. C. Jennings** : In Sheffield the industrial consumption—and 80% of the gas which we supply is supplied for steelworks' purposes—does vary. Even one consumer can make an appreciable difference to us. As a rule the consumers keep us well in touch with what their programmes are. If your steelworks programme is altering, it might affect the tie-up of the control room. I take it that you are in touch in that way ?

Mr. **J. S. Bryan** : Yes, we are in complete touch with all departments, and they at once let us know of any alteration in their requirements. We neutralize the variations from the set plan as soon as they happen.

Mr. **W. R. Brown** (Messrs. Ashmore, Benson, Pease and Co., Ltd., Stockton-on-Tees) : You give some useful figures for your gas velocities. Are those N.T.P. velocities, particularly for the crude-gas mains ?

Mr. **J. S. Bryan** : Yes.

The **Chairman** : The works with which I am connected has a number of problems similar to those raised by other speakers, and it may be of interest to mention what has happened there. With regard to the gas-cleaning plant, it is evident that everybody all over Great Britain has had in mind the question of adopting the American principles of superimposed gas-cleaning plant, but no one has so far mentioned one point which the British precipitation people put forward, and that is that the American superimposed type of plant is, by the nature of its design, forced to have all the electrodes in parallel, whereas the Lodge-Cottrell horizontal system has them in series and has the banks cross-connected, so that if one bank trips out the whole of the gas going through that section of the precipitator is not dirty.

This, we are persuaded, is an important improvement, but it brings with it an increase in space requirements, because you are forced then to have the precooler separate from the precipitation unit. That seems to us, after some years of experience with the same type of plant as is used at Ebbw Vale, to be not necessarily a disadvantage, because if you have trouble on a precooler you can lay it off without laying off the pretreater with it. The only advantage of having the whole plant right on top of the furnace is the elimination of the dirty-gas main, but if you have a modern efficient centrifugal type of dustcatcher you do not have very serious trouble in your dirty-gas mains, if you can design them to be of reasonable length.

Reference has been made to lining the crude-gas main. During the war, when we were on 100% home ore—and I expect that all those who were on home ore had the same trouble—we had water pouring out of our dirty-gas main, though it was lined from end to end, owing to the extraordinarily low top-gas temperatures ; but now that we are back on foreign ore we never have any water at all. You have to vary your tactics according to the ore with which you are dealing.

With regard to the control room, we have had arguments on whether to have the control room in the power station for everything or whether to locate it near to the producing unit, and the gas-cleaning plant. Our fuel people and the blast-furnace manager were very much in favour of having the control room so situated that the manager could speak to the people who were controlling the valves, and so on, on the gas-cleaning plant, and so that one could shout to the other in the event of communications breaking down. I do not know whether their judgment was affected by war-time experiences, but they were all enthusiastically in favour of that, and so in the end we decided to have an electricity-control room in the power station and a gas-control room at the gas-cleaning plant.

I was very interested to hear the discussion of air *versus* steam for atomization. That is a very important question, because on a big open-hearth shop the quantity of steam that it is necessary to have (and, incidentally, the treated water, if it is going through a boiler plant, that you waste by blowing down the atomizers) if indeed compressed air is more efficient, is considerable. I hope that the technicians will soon make up their minds whether it is possible to use air or not.

I should like to know why we cannot use pressure atomization. The *Queen Mary*, which has run on fuel oil for much longer than any steelworks in this country, has an arrangement whereby, when changing from so many gallons an hour to another figure, a change is made from one nozzle to another, and it is simply a question of using the right type of nozzle for the consumption, with no use of air or steam. Why do not we try that out ?

With regard to oil in gas-holders, I believe that the authors use tar. Cannot the oil people supply a demulsification oil which will automatically get the water out ?

I wonder whether anybody here has been puzzled by the nitrogen balance ? The nitrogen going into the furnace *via* the blowers is very different from the nitrogen coming out at the other end in the clean gas. Everybody says, " It is different, and that is all there is about it ; why

worry ?" I should be interested to know, however, why it is so different. Anybody who has never operated a steelworks is apt to say that the nitrogen gas is constant; so much goes in, so much comes out, and that gives the capacity of the cleaning plant; if you blow so many cubic feet a minute, you are blowing so many cubic feet of nitrogen in. But it is not so, and many plant makers have tripped up over this simple fact. I think that it is a mistake on the part of the operators that they have not told the plant makers that there is a serious discrepancy in the nitrogen gas balance, and that if a furnace blows 50,000 cu. ft. of air per minute they cannot work out from that how much gas is coming out the other end merely by assuming a constant quantity of nitrogen going in and coming out.

Mr. **F. A. Gray**: The Chairman asks why we do not use pressure atomization. I believe that it has been tried in this country, but has not been satisfactory. I think that the trouble is the size of the nozzle. It is necessary to have a very tiny hole to get atomization by this method, and the slightest dirt will block it up. Carbonization or carbon deposit at the burner tip would thus have a serious effect. It would also be necessary to change the nozzles to cover different rates of flow, as the normal pressure jet has a limited turn-down capacity.

Mr. **D. J. Heslop** (Ministry of Fuel and Power): With regard to the question of the use of the pressure-jet nozzle, which was previously mentioned by the Chairman, the shape of the flame derived from it is generally that of a hollow cone, and in the steel industry a flame of a long billowing nature is required. In that connection a previous speaker has mentioned atomizing pressures of 80–150 lb./sq.in., but I do feel that such pressures tend to give a torch-like flame far removed from the soft billowing flame travelling down the furnace which you require. For this purpose an atomizing pressure of about 30–40 lb./sq.in. at the burner, with a maximum of 50 lb./sq.in., would produce the ideal flame.

With regard to the actual burning temperature for the oil, mention has been made of preheat temperatures of 50–80° F. above the flash point of the oil. I wonder whether these are temperatures of oil in the ring main, and not those at which the oil is being atomized, because there may be several feet of what might be termed "dead leg" pipe between the ring main and the burner, which, because of the existence of water-cooling arrangements or other circumstances, may be cooled to a temperature below that of the actual indicated ring-main temperature.

For a fuel oil of 950 sec. Redwood No. 1 viscosity at 100° F., a temperature not exceeding 220° F. is required for the oil at the atomizing point.

To revert to the Chairman's question about the use of the pressure-jet burner: this type of burner flame requires support by its combustion air under forced-draught conditions through an air register, and the combustion air, in order to produce smoke-free combustion, has to be very carefully directed.

I think that this is the explanation of why the pressure-jet burner is not suitable for steel-furnace work. In addition, as oil to the quantity of 20 gal./hr. can be passed through a nozzle hole of something like 0·06 in. dia., it will be seen that it is necessary to have not only very fine orifices but also very carefully prepared atomizing surfaces, which would not stand up so well to the comparatively rough treatment which the ordinary rear-atomizing burner can withstand.

Mr. **A. H. Pinder** (Ministry of Fuel and Power): I had a number of question to ask and comments to make, but in view of the shortness of time will cut them down. I should, however, particularly like to comment on the question of instrumentation. An earlier speaker has referred to the operatives' dislike of instruments. This is fairly common in all industries and has to be eliminated in some manner if full benefit is to be obtained. Otherwise we get old practices continuing to be applied to new processes to which they are not applicable. In a sense the maintenance of instruments is even more important than their installation. In this connection it should be known that the Fuel Efficiency Branch of the Ministry of Fuel and Power are running courses in the various Regions on day-to-day instrument maintenance, the object being to train works fitters and plant engineers in the work. We should like to be of as much use as possible to the iron and steel industry in this and would welcome their co-operation in sending suitable men to obtain training from the courses.

Waste-heat boilers have been mentioned, and I should like to know if the authors can provide any figures for equivalent fuel savings arising from the use of their waste-heat boilers ? As you know there is great difficulty in obtaining fuel equipment at the present time, and endeavours are being made to assess accurately the figures of fuel saving resulting from the operation of new appliances so that they may be used to form a basis for granting improved priority to such equipment.

On the question of oil-fired plant, did I understand the authors to say that they were preheating the same oil to different temperatures for different furnaces on the same ring main ?

Mr. **J. S. Bryan**: No. We have two systems at the present time, one for fuel oil and one for creosote-pitch. The two systems are completely separate.

Mr. **A. H. Pinder**: But you are having to vary your preheat temperatures almost from day to day ?

Mr. **J. S. Bryan**: Not to that extent. We vary them according to the atmospheric temperature, particularly with creosote-pitch; we keep fairly constant with the fuel oil. We vary the pressures used from furnace to furnace. We experiment and find the conditions which best suit a particular furnace; that is what it amounts to.

Mr. **A. H. Pinder**: That is what I understand usually happens or should be the practice. There is another question which is exercising our minds considerably at the moment in view of the wide scale of oil conversion, much of it improvised, and that is as to what *pro rata* efficiencies are being obtained in conversions of furnaces from gas firing to oil. Is it the opinion of people who have so converted that equal thermal efficiencies are obtained in practice or are they better or worse, after conversion than they were on gas ?

Mr. **J. S. Bryan**: I cannot give any figures off-hand for the equivalent fuel saving, but the steam generated at 160 lb./sq.in., and 420° F. is equivalent to a credit of about 1,500,000 B.Th.U. per ton of steel for the steel-plant.

We have had better thermal efficiencies from the burning of liquid fuel than from the burning of gaseous fuels. We usually run on blast-furnace and coke-oven gases at about 5,000,000–5,500,000 B.Th.U./ton of steel, but we have been as low as 3,700,000 with creosote-pitch/coke-oven-gas firing. We have had better results from oil burning, but that is not taking into consideration the refractory costs.

CORRESPONDENCE

Dr. **D. F. Marshall** (The Park Gate Iron and Steel Co., Ltd., Rotherham) wrote: The question of blast-furnace-gas cleaning has for many years been a very controversial but somewhat neglected subject, as is evinced by the varied types of gas-cleaning plants operating at ironworks in this country.

Cleaning the entire gas yield from two or three blast-furnaces down to a cleanliness of 0·01 g./cu.m. is

frequently attempted and involves complicated plant with either a very large capital cost or high running cost, or even both. The presentation of this paper suggests that the time is opportune for a detailed investigation into the whole subject. We might, for example, devote attention to certain questions, such as :

(1) The degree of cleanliness required to assure continuation of operation in mains, gas-holders, and valves, particularly where control valves having fine clearances between valves and seatings are used.

(2) Generally speaking, gas for stoves or coke ovens should be cleaned to about 0·01 g./cu.m., but experience in America and at some plants in this country has shown that some pitfalls may follow excessively fine cleaning, resulting from the increased alkalinity of the residual dusts. We ought to know, therefore, what is the nature of residual dusts and fumes in a gas as it is progressively cleaned.

(3) In the present need for fuel economy we ought to have an answer to the question of the value of increased boiler efficiency when using gases of 0·5, 0·05, and 0·01 g./cu.m. over extended periods.

(4) Is the use of wetting agents entirely precluded from blast-furnace-gas cleaning, since the dust in certain forms is notoriously difficult to remove by water streams or sprays ?

(5) As yet there has been no published co-ordinated research on the physical and chemical properties of dusts from blast-furnaces using different ores.

(6) It is very significant also that many design decisions may be influenced, perhaps unduly, by results obtained from dust tests; tests which are technically very difficult to carry out and should certainly be investigated with a view to standardization at the earliest possible moment.

In the section on fuel-oil utilization, the question of oil heating is worthy of careful consideration.

If the control over oil heating is erratic the flow at the furnace will also be erratic. There also is a secondary effect which may be very important. Oil-flow measurement is very necessary to efficient furnace operation, and the variation of temperature and oil viscosity by upsetting meter calibrations may again cause further departures from steady conditions at the furnace.

On our own plant we have favoured heating all the oil in heaters situated between the pump deliveries and the circulating mains. In conjunction with these heaters, thermostatically controlled tracers are used on the circulating mains. In practice this arrangement has given very tight control ± 5° F. over the oil-circulating temperature, which has enabled us to operate oil flow meters well within the standard flow-meter tolerances of ± 2% accuracy. We have been within ±1% over extended checking periods.

It is often claimed that the best method of furnace control is the fully automatic furnace. Anything short of this may be influenced by faulty instructions, faulty operators, or inadequate maintenance of instruments.

Our own experiences during the past eight months have indicated that time spent considering these three points in the early stages will be amply repaid later.

The list of instruments to be erected on the control panel (p. 124) is very comprehensive and one therefore wonders if the authors have some definite reason for not including roof-temperature recorders, particularly since the roofs are not very high.

Mr. **C. E. Wilson** (Messrs. Ashmore, Benson, Pease and Co., Ltd., Stockton-on-Tees), wrote : Some comment has been made during the discussion on the respective merits of the water seal and the goggle valve as isolating mediums. Any goggle valve ensures absolute isolation up to pressures which would burst the steel disc, and so probably burst the gas mains also. This pressure in the case of the thermal-expansion goggle valves used on the majority of modern blast furnaces, would be in the region of 100 lb./sq.in. It would be fantastic to imagine a water seal capable of isolating against pressures of this magnitude. It is admitted that through negligence a goggle valve can leak, but the leaking gas then passes harmlessly to atmosphere, and not into the isolated section of the gas system. Through negligence or corrosion a water seal can also leak, but the gas then passes into the system from which it should be isolated. In essence therefore the goggle valve is bound to be superior to the water seal, and the only questions that can arise are whether its cost is prohibitive or its reliability open to doubt.

The thermal-expansion goggle valve (as illustrated in the paper), obtains its closure—which incidentally is steel to steel—by a law of physics rather than by mechanism, and this makes its dependability absolute ; this assertion may appear somewhat sweeping, but it is borne out by practical experience, for only by corrosion and erosion (faults to which any valves or seals are susceptible), can the working of the valve become faulty.

I have seen the design drawings of a great number of furnaces that have been erected during the last 10 to 12 years and can recall that in almost all cases a goggle valve is preferred to a water seal for the provision of isolation from the gas system. Water seals are certainly very decidedly in the minority.

AUTHORS' REPLIES TO CORRESPONDENCE

Mr. J. B. R. Brooke and Mr. **J. S. Bryan** wrote : We are in complete agreement with Dr. Marshall regarding the need for an investigation into the subject of gas cleaning. We are following the modern trend by installing an electrostatic plant to clean the entire gas yield, which we hope will give the following advantages :

(1) The engineering problems of distribution will be alleviated.

(2) With the use of clean blast-furnace gas, the stove-checker openings can be decreased and pressure burners installed to give a more efficient plant.

(3) Clean gas should give increased boiler efficiency and will certainly obviate the necessity for regular cleaning of burners.

These factors should justify the installation of the plant, but, as Dr. Marshall indicates, there is no published information to guide one in making a decision.

The ascertaining of dust contents raises a point which was not stressed in the paper. The instrument which we use gives only a comparative reading for our plant, by which from experience gained, we can forecast the cleaning operation, water quantities, etc., required for the distribution system. Before comparison can be made between different plants, the standardization of instruments and procedures must first be made.

The utilization of fuel oil has been extensively dealt with both in the paper and the discussion, and I agree with all Dr. Marshall's remarks. With reference to the use of roof-temperature recorders, we have considered that roof pressure gave a more reliable guide to furnace operation, but we intend to instal roof-temperature recorders at one furnace in the very near future.

We should like to thank Mr. Wilson for his contribution on the respective merits of water seals and goggle valves.

For furnace-isolation purposes, we entirely agree that goggle valves are essential for reliability's sake, but on the distribution system, for isolating sections of the main, the water seal has, we think, the advantage, owing to reduced cost and satisfactory reliability.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE
Autumn Meeting, 1948

The Autumn Meeting of The Iron and Steel Institute will be held on Wednesday and Thursday, 10th and 11th November, 1948. The President, Sir Andrew McCance, D.Sc., F.R.S., will be in the Chair.

The Sessions will take place at the Institute's Offices, 4, Grosvenor Gardens, London, S.W.1, and arrangements will be made for Members to obtain Buffet Luncheons in the Joint Library, between the morning and afternoon Sessions.

Full details of the programme will be given in the next issue of the *Journal*.

Special Summer Meeting in Norway, 1949

Arrangements for the Special Summer Meeting in Norway next year are well advanced. A circular giving full information will be issued shortly and Members will be invited to register during the Autumn. A fee of £10 will be payable on registration. The inclusive cost is likely to vary between £55 and £85 according to the type of cabin selected in the M.S. *Venus*. The dates will be from 28th May to 7th June, 1949.

The chief technical interest of the meeting will lie in the study of the application of electricity to various industrial purposes. Industry in Norway has been built up on the basis of hydro-electric power, and interesting developments have been made in the application of electricity to heating and smelting. Visits will thus be paid to plants where electricity is used for the smelting of iron and steel and ferrous alloys, to power stations, to a paper factory, and to a glassworks, where electric furnaces are used, as well as to aluminium, nickel, and zinc refineries. The programme also includes visits to medium and light steel section mills, various finishing plants, a shipbuilding yard, canning factory, etc. Although the metallurgical works are relatively small, they are up-to-date and efficient.

A Joint Meeting is being arranged with the Norwegian Metallurgical Society, at which Dr. J. Görrissen, President of the Society and Director of Research at Kristiania Spigerverk, will preside. A number of papers specially prepared for the occasion will be discussed.

The Norwegian Reception Committee, of which Mr. Gunnar Schjelderup, Managing Director of Kristiania Spigerverk, has agreed to be Chairman, is arranging an attractive social programme, in which Ladies are invited to take part. This will include sightseeing excursions in Oslo, Kristiansand, and Bergen, and visits to the Hardanger and Sogne fiords, two of the most beautiful of the Norwegian fiords. Members and their Ladies will be invited to dinners and dances at Oslo and Bergen, and to a number of other social functions.

As previously announced, the Bergen Steamship Co., Ltd., has agreed to make available the M.S. *Venus*. Members and Ladies will live on board ship. The *Venus* is the largest ship sailing regularly between this country and the Continent ; she has a speed of 20 knots and a tonnage of 7000. She has been completely reconditioned since the war and re-entered the normal passenger service between Newcastle and Bergen in May, 1948. Dining-saloon and lounge accommodation is exceptionally good.

The *Venus* will leave Newcastle on the evening of Saturday, 28th May, 1949, and return there on the morning of Tuesday, 7th June, 1949, thus including Whitsun weekend. Two days will be spent at Oslo, during which there will be a number of visits to works, a technical meeting, banquet, and other entertainments. It is proposed then to visit the Hardanger fiord and on the way to spend a day at Kristiansand in order to see the works and other places of interest in the neighbourhood. In the Hardanger fiord visits will be paid to works, and opportunities given to see something of the fine scenery for which the fiord is famous. The ship will then call at Bergen, where Members and Ladies will visit works, take part in sightseeing excursions, and be entertained at a dinner and dance. Finally, a two-day visit will be paid to the Sogne fiord, with the object of seeing the important hydro-electric and metallurgical establishments at Ardal, and of making excursions in the surrounding mountains.

Joint Committee on Metallurgical Education

REPORT ON PROGRESS FOR THE PERIOD FROM 1ST JANUARY, 1947, TO 30TH JUNE, 1948

Nine meetings of the Committee were held during the period under review, including a Special Meeting held on the 7th May, 1948, to enable members to meet and interchange views with Dr. Robert F. Mehl, of the Carnegie Institute of Technology, Pittsburgh, Chairman of the Advisory Committee on Metallurgical Education of the American Society for Metals.

The following is a list of members as at 30th June, 1948, representing Industry, The Iron and Steel Institute, The Institution of Mining and Metallurgy, The Institute of British Foundrymen, The Institute of Metals, Institution of Metallurgists, Universities, City and Guilds of London Institute, The Association of Technical Institutes, and The Association of Principals of Technical Institutes :

Professor LESLIE AITCHISON, D.Met. (*Chairman*)

Professor G. WESLEY AUSTIN, O.B.E.	Mr. E. D. MCDERMOTT,
	Mr. W. A. C. NEWMAN, O.B.E.
Mr. G. L. BAILEY, M.Sc.	Mr. G. PATCHIN
Professor C. W. DANNATT	Dr. L. B. PFEIL, O.B.E.
Dr. C. H. DESCH, F.R.S.	Sir ARTHUR SMOUT, J.P.
Mr. J. W. GARDOM	Mr. R. B. TEMPLETON
Dr. E. GREGORY	Mr. D. R. O. THOMAS
Mr. R. A. HACKING, O.B.E.	Professor F. C. THOMPSON, D.Met., M.Sc.
Dr. J. E. HURST, J.P.	
Mr. J. SINCLAIR KERR	Dr. A. M. WARD
Mr. E. J. LAWFORD	Mr. J. WILSON

Dr. C. H. Desch, whilst continuing his membership of the Committee, resigned the Chairmanship on the

3rd June, 1947, and Professor Leslie Aitchison was appointed Chairman from that date.

During 1947 the Committee continued to give assistance to parents and students seeking information about facilities for metallurgical education, to compile information on metallurgical films, and to arrange for their loan to Colleges, Schools, Local Societies, and Works.

A second and revised edition of the brochure "*Metallurgy—A Scientific Career in Industry*" has been prepared and was published in May, 1948; it contains the latest available information about courses in metallurgy at Universities and Technical Colleges. Copies have been sent, among others, to all Local Education Authorities, the Principals of Technical Colleges, and Headmasters of Secondary Technical Schools. Over 6000 copies of this brochure have been distributed.

The work of the Committee includes:

(1) Consideration of the general requirements for providing education for metallurgists of all grades.

(2) Assisting in every way possible in the provision of the means by which these requirements can be secured at the different levels.

(3) Making known throughout the Secondary and Public Schools the opportunity offered by metallurgy as a career.

(4) Providing parents, guardians, careers masters, and others, with full details of the educational facilities available to fit boys for various careers in metallurgy.

(5) Keeping continuous touch with industry in order to ascertain in what respects the young metallurgist is considered to fall short of the appropriate standard when he enters the metallurgical industry: (*a*) With a University Degree; (*b*) with a National Certificate in Metallurgy or qualification of a similar standard; (*c*) with other qualifications from a Technical School or College.

Ascertaining how far his falling short of the highest standard can be laid at the door of metallurgical education and taking such remedial steps as may be possible.

(6) Taking appropriate steps for carrying its policy into effect, including: (*a*) Discussions and meetings with the interested people in Industry, Schools, Technical Colleges, Universities, and Government Departments, in order that views may be exchanged; and (*b*) the preparation of memoranda addressed to the various bodies which may be concerned and the publication of the Committee's views and suggestions.

(7) The consideration of special matters of an important nature, such as entrance qualifications to University Schools of Metallurgy. A pamphlet giving the Committee's "*Recommendations on Qualifications for Entrance to University Schools of Metallurgy*" was published in April, 1948, and widely circulated to the various interested bodies, and the recommendations have been published in the Press and in the Journals of the participating Institutes.

NEWS OF MEMBERS

▶ Mr. W. R. BERRY has been elected President of the Leeds Metallurgical Society in succession to Professor A. Preece and has accepted an invitation to become an Honorary Member of Council of The Iron and Steel Institute during his period of office.

▶ Dr. MAURICE COOK is the new President of the Institution of Metallurgists, and Mr. E. W. COLBECK and Mr. A. J. MURPHY have been appointed Vice-Presidents.

▶ Mr. F. M. DAVIS has recently joined Messrs. Swan, Hunter and Wigham Richardson, Ltd., of Wallsend, as a metallurgical chemist.

▶ Mr. K. S. GANAPATI recently obtained the degree of B.Sc. in Metallurgy at Durham University.

▶ Mr. H. M. HENDERSON has been elected President of the Lincolnshire Iron and Steel Institute in succession to Wing Commander J. B. R. Brooke and has accepted an invitation to become an Honorary Member of Council of The Iron and Steel Institute during his period of office.

▶ Dr. B. JONES, chief metallurgist, and Mr. G. I. RUSHTON, general works manager, of the Whitehead Iron and Steel Co., Ltd., have been appointed Special Directors of the company.

▶ Dr. W. D. JONES has been awarded an honorary degree of Doctor of Technical Sciences, in recognition of his services to the development of powder metallurgy. The award was made at the International Conference on Powder Metallurgy held recently at Graz.

▶ Mr. A. T. LEDGARD has been appointed blast-furnace manager at the Redcar plant of Messrs. Dorman, Long & Co., Ltd.

▶ Mr. G. D. MCADAM has recently been awarded the degree of Doctor of Philosophy of Sheffield University, and the Brunton Medal for metallurgical research.

▶ Mr. J. M. MCSHANE has left the Broken Hill Proprietary Co., Ltd., and is now assistant general manager (technical) of the Australian Gas Light Company, Sydney.

▶ Mr. F. R. NELSON has left Armstrong Siddeley Motors, Ltd., Coventry, and has taken up a post with Humber, Ltd., Coventry.

▶ Mr. B. F. OLDS has accepted a post as technical assistant at Messrs. Hadfields, Ltd., Foundry Division, East Hecla Works, Sheffield.

▶ Mr. W. D. PUGH has succeeded Mr. F. Pickworth as Managing Director of the Darlington Forge, Ltd. Mr. Pickworth will continue to hold office as Chairman of the company.

▶ Mr. H. MCK. SKELLY is now engaged on metallurgical work in the research laboratories of the Aluminium Company of Canada, Ltd., and his address is 145, Colborne Street, Kingston, Ontario, Canada.

▶ Mr. A. W. TOWN has now left Cambridge University, having obtained first-class honours in metallurgy, and will shortly be taking up a post in the steel-melting shop of Messrs. Hadfields, Ltd., Sheffield.

▶ Mr. F. C. N. WHITAKER has left Messrs. Wm. Jessop and Sons, Ltd., Sheffield, and is now with the Birtley Company, Birtley, Co. Durham.

Obituary

The Council regret to record the deaths of:

MR. THOMAS MACDONALD ROBERTSON, research metallurgist at the Clydebridge Steelworks of Messrs. Colvilles, Ltd., Glasgow, on 16th August, 1946.

Mr. JAMES SMITH, of Liverpool on 30th October, 1947.

CONTRIBUTORS TO THE JOURNAL

John H. Cook—Metallurgist engaged in research with the British Iron and Steel Research Association. After graduating in fuel and metallurgy at Leeds University in 1944, Mr. Cook was appointed assistant to the chief development engineer in the newly formed research and development department of Messrs. Jonas Woodhead and Sons, Ltd. He joined B.I.S.R.A. in 1945 to work on the experimental open-hearth furnace.

F. Lesley Robertson, M.C., B.Sc., F.I.M.—Steelmaking consultant to Messrs. John Summers and Sons, Ltd. Mr. Robertson was born in Glasgow in 1887 and was educated at Routenburn Preparatory School and at Loretto. In 1908 he graduated B.Sc., with special distinction in chemistry, at Glasgow University. After serving a student-apprenticeship in Gartsherrie Iron Works he joined the Brown-Firth Research Laboratories

G. T. Shoosmith

E. Rogers

A. W. Swan

under the late Mr. Harry Brearley, and two years later became a member of the melting-shop staff.

In 1914 Mr. Robertson was appointed melting-shop manager to the Steel Company of Japan. A year later he returned to this country, and after serving in the Royal Inniskilling Fusiliers and in the Royal Engineers, was in 1919 appointed melting-shop manager at Blochairn Steelworks. In 1933 he took up a similar position with the Shelton Iron, Coal, and Steel Co., Ltd.

Mr. Robertson, who commanded the 52nd (Lowland) Divisional Signals from 1929 to 1934, retiring with the rank of Brevet Colonel, was appointed to his present post in 1940.

E. Rogers, B.Sc.—Senior scientific officer at the British Iron and Steel Research Association. Mr. Rogers graduated in 1943 at King's College, Newcastle-upon-Tyne, and from then until 1946 was concerned with research and development of measuring instruments at the Royal Aircraft Establishment, Farnborough. At present at the B.I.S.R.A. Physics Laboratories, Mr. Rogers is engaged in research and development of instruments and their application to steelmaking.

A. W. Swan, B.A.Sc., A.M.I.Mech.E.—Head of the Statistical Section of the Research and Development Department of The United Steel Companies, Ltd. Mr. Swan was educated at George Watson's Boys' College, Edinburgh, and at the University of Toronto, where he graduated in mechanical engineering. For some years after his graduation he obtained experience in production engineering, in Canada with the Canadian Ingersoll-Rand Co., Ltd., and in England with the Sterling Telephone Co., Ltd. He later transferred to market research, first with Evershed and Vignoles, Ltd., and then with The United Steel Companies, Ltd. During the recent war, Mr. Swan was employed by the Ministry of Supply to instal statistical quality control in the Royal Ordnance filling factories. He was also on loan to the Ministry of Production to assist with the Quality Control Panel in Birmingham, and to the Ministry of Education. At the end of the war, Mr. Swan returned to The United Steel Companies, Ltd., to form the Statistical Section.

G. T. Shoosmith, M.A., A.M.I.C.E., M.I.Mech.E., M.I.Mar.E.—Chief engineer of Messrs. Wm. Cory and Son, Ltd., and of their subsidiaries. Educated at Oundle and Cambridge, Mr. Shoosmith was engaged in the designing and construction of chemical plant with the Davison Chemical Corporation, Baltimore, U.S.A., from 1929 to 1931. In the following year he was appointed marine engineer and Diesel traction engineer to the English Electric Co., Ltd., and held this position until 1938 when he joined Messrs. Wm. Cory and Son, Ltd. He became chief engineer in 1941. During the recent war Mr. Shoosmith acted as technical adviser to the Coal Division of the Ministry of War Transport.

IRON AND STEEL ENGINEERS GROUP

The Eighth Meeting of the Iron and Steel Engineers Group will be held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 24th November, 1948, commencing at 10.30 A.M. Three papers are to be presented and discussed :

"*Belt Conveyors, Bunkers, and Chutes for Iron and Steel Works*," by J. Brimelow (to be published in the October, 1948, issue of the *Journal*),

"*Ore Discharging*" by G. T. Shoosmith (published on page 75 of this issue),

"*Specialized Rolling Stock for Iron and Steel Works*," by T. H. Stayman and D. R. Brown (to be published in the October, 1948, issue of the *Journal*).

There will be a Buffet Luncheon in the Joint Library in connection with the meeting.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Staff

Dr. A. M. BURDON, Standardization Officer of the British Iron and Steel Research Association, has been transferred to the staff of the British Iron and Steel Federation and will be working for the Market Development Department under Mr. T. Stevenson.

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

In addition to the List of Council and Officers of the Swansea and District Metallurgical Society printed in the August, 1948, issue of the *Journal*, Professor Hugh O'Neill, D.Sc., M.Met., F.I.M., and Mr. H. Phillips, M.I.Mech.E., have now been co-opted as Members of Council. Capt. H. Leighton Davies has again agreed to represent the Institute on the Society's Council.

INSTITUTION OF METALLURGISTS

Refresher Course

A refresher course on "The Mechanical Working of Metals" will take place at Ashorne Hill, near Leamington Spa, from Friday, 1st October, to Sunday, 3rd October, 1948. The lectures to be given are as follows :

Friday, 1st October, 1948

8.30–9.30 P.M. : "*The Mechanism of the Deformation of Metals*," by Dr. E. Orowan, F.R.S.

Saturday, 2nd October, 1948

9.30–11.0 A.M. : "*The Removal of the Effects of Mechanical Working*," by Dr. L. B. Pfeil, O.B.E.

11.30 A.M.–1.0 P.M. : "*Rolling*," by Dr. Hugh Ford.
2.30–4.0 P.M. : "*Extrusion*," by Dr. R. Genders, M.B.E.

Sunday, 3rd October, 1948

9.30–11.0 A.M. : "*Deep-Drawing and Pressing*," by Professor H. W. Swift.
11.30 A.M.–1.0 P.M. : "*Cold Drawing*," by Professor F. C. Thompson.

In addition there will be a display of metallurgical films and an entertainment during the evening of Saturday, 2nd October, 1948.

NEWS OF SCIENCE AND INDUSTRY

Sondes Place Research Institute

Sondes Place Research Institute, Dorking, Surrey—the Industrial Research Laboratory of Messrs. Mactaggart and Evans, Ltd., was opened on Friday, 18th June, 1948, by Sir William J. Larke, K.B.E., D.Sc.

Coal Tar Research Association

The administrative offices of the Coal Tar Research Association are now situated at 9, Harley Street, London, W.1. (telephone Langham 1778).

Technology of Refractory Materials

A course of ten lectures on "*The Technology of Refractory Materials*," will be delivered by Mr. L. R. Barrett, at 7.0 P.M. on Wednesday evenings from 6th October to 8th December, 1948, at Northampton Polytechnic, St. John Street, London, E.C.1. The syllabus is extensive and includes the raw materials and products of the refractories industries, the mechanical and thermal properties of refractories, physico-chemical reactions, moulding sands, and industrial hazards in the silicate industries. Admission to the course is by personal enrolment at the Polytechnic office.

Design and Operation of Fuel-Fired Furnaces

A course of twenty lectures on "*The Design and Operation of Fuel-Fired Furnaces, with Special Reference to Recent Developments*," will be held at 7.0 P.M. on Tuesday evenings, commencing on 5th October, 1948, at Northampton Polytechnic, St. John Street, London, E.C.1. The course will cover the production and properties of solid, liquid, and gaseous fuels ; the design and operation of gas-fired and oil-fired furnaces ; and the firing of power-station boilers. The lecturers will be Mr. R. A. Acton-Taylor, Mr. G. F. J. Murray, and Mr. R. F. Hayman. Admission to the course is by personal enrolment at the Polytechnic office.

DIARY

5th Oct.—EBBW VALE METALLURGICAL SOCIETY—Chairman's Address : "*Development in Steelworks Plant*," by H. F. Padbury—Lesser Workmen's Hall, Ebbw Vale, 7.0 P.M.

7th Oct.—LEEDS METALLURGICAL SOCIETY—"*High-Speed Photography*," by G. A. Jones—Chemistry Department, Leeds University—7.0 P.M.

7th Oct.—LIVERPOOL METALLURGICAL SOCIETY—"*New Lamps for Old*," by Professor J. H. Andrew—9 The Temple, 24 Dale Street, Liverpool—7.0 P.M.

8th–9th Oct.—L'ASSOCIATION TECHNIQUE DE FONDERIE—22nd Annual Congress. Under patronage of the Ministers of National Economy, of Industry, of Commerce, and of National Education—Paris.

16th Oct.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Presidential Address, by T. J. Canning.

18th Oct.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Presidential Address, by B. W. Doncaster—Royal Victoria Station Hotel, Sheffield, 6.15 P.M.

18th Oct.—Joint Meeting of Iron and Steel Engineers Group, Institution of Mechanical Engineers, and Cleveland Institution of Engineers—"*Some Possible Future Developments in the Manufacture of Iron and Steel in Great Britain*," by W. F. Cartwright—Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough—6.30 P.M.

21st – 22nd Oct.—BRITISH IRON AND STEEL RESEARCH ASSOCIATION—Conference on Foundry Core Bonding Agents—Ashorne Hill, near Leamington Spa.

TRANSLATION SERVICE

(The previous announcement was made in the August, 1948, issue of the *Journal*, p. 430.)

TRANSLATIONS AVAILABLE

No. 352 (Swedish). G. MALMBERG : "The Effect of Specimen Shape on the Elongation in Tensile Testing." (*Jernkontorets Annaler*, 1944, vol. 128, No. 6, pp. 197–245).

No. 353 (German). F. LÜTH : "The Moisture in Industrial Gases. Part II.—The Application of the Moisture Calculation." (*Archiv für das Eisenhüttenwesen*, 1930, vol. 4, Oct., pp. 185–192).

No. 354 (Dutch). M. G. VAN DER STEEG : "The Heat-Treatment of Chains." (*Metalen*, 1947, vol. 1, June, pp. 190–192 ; July, pp. 207–209).

PAPERS ACCEPTED FOR TRANSLATION SINCE THE LAST ANNOUNCEMENT

(French). M. BRUN : "Factors Affecting the Coke Consumption in the Blast-Furnaces in the Briey Region." (*Revue de Métallurgie, Mémoires*, 1945, vol. 42, Sept., pp. 273–285 ; Oct., pp. 308–320 ; Nov., pp. 347–358 ; Dec., pp. 393–401).

(German). K. GUTHMANN : "Blast-Furnace Output per Unit Hearth Area." (*Stahl und Eisen*, 1947, vol. 66–67, Dec. 4, pp. 425–427).

(German). (*a*) JOHANNA HUNGER and R. SEELIGER : "The Presentation of Relief in the Ultra-Microscope by Means of Pressed and Double-Layer Replicas." (*Metallforschung*, 1947, vol. 2, Mar., pp. 65–69).

(*b*) H. MAHL : "Electron-Micrographs of Steel Fractures." (*Metallforschung*, 1947, vol. 2, June, pp. 186–188).

(German). F. KOFLER and G. SCHEFELS : "Flow Processes in the Hearth of Open-Hearth Furnaces." (*Stahl und Eisen*, 1933, vol. 53, Feb. 16, pp. 162–167).

(German). H. SCHUMACHER : "Relationship between Blast-Furnace Burden and Fuel Economy in Iron and Steel Works." (*Stahl und Eisen*, 1947, vol. 66–67, Nov. 6, pp. 375–379).

(German). P. WOLF : "The Development of the Blast-Furnace Profile in Different Countries." (*Stahl und Eisen*, 1947, vol. 66–67, Dec. 4, pp. 411–416).

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

Increase of Charges

As previously announced, the price of translations has been increased, as from 1st July, 1948, to £1 for one copy of any translation in the Series, and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance.

Translations in the Series are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

	PAGE
Ores—Mining and Treatment	99
Fuel—Preparation, Properties, and Uses	99
Temperature Measurement and Control	100
Blast-Furnace Practice and the Production of Pig Iron	101
Production of Steel	103
Foundry Practice	104
Heating Furnaces and Soaking Pits	107
Heat-Treatment and Heat-Treatment Furnaces	107
Forging, Stamping, Drawing, and Pressing	108
Machinery for Iron and Steel Plant	109
Lubricants and Lubrication	110
Welding and Flame-Cutting	110
Machining and Machinability	111
Cleaning and Pickling	111
Protective Coatings	112
Powder Metallurgy	113
Properties and Tests	113
Metallography	117
Corrosion	118
Analysis	118
Book Notices	119
New Publications	120

ORES—MINING AND TREATMENT

Completes New Laboratory for Study of Taconite Concentration. (Iron Age, 1948, vol. 122, May 10, pp. 108, 110, 112). A new laboratory has been established by the Oliver Iron Mining Co., Duluth, Minnesota, to develop the extraction of iron-bearing minerals from taconite and other ores. Microscopic, petrographic, mineralogical, and chemical tests are carried out on cores from ore bodies : a batch-testing plant for investigating extraction procedures deals with up to 100 lb/hr, while a pilot plant can handle up to 1 ton/hr. Both are flexibly arranged so that various procedures may be studied. J. P. S.

U.S. Steel Pushes Ore Research. (Iron and Steel Engineer, 1948, vol. 25, May, pp. 92–93). A brief description is given of the new ore research laboratories of the United States Steel Corporation at Duluth, Minnesota, where the concentration of taconite by froth flotation and magnetic separation is being studied.—R. A. R.

The Ore-Preparation Plant at the Workington Branch of the United Steel Companies, Ltd. (Journal of The Iron and Steel Institute, 1948, vol. 158, May, pp. 73–76).

The Mechanism of Sintering Iron Ores. P. E. Henry. (Centre de Documentation Sidérurgique, 1947 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 3). Preliminary tests on the sintering of Moroccan iron and manganese ores are described and the principle of sintering is explained. An account is given of the preparation of the charge including the mixing, the quantity of water to be added, the desired degree of plasticity, composition and optimum particle size. The bed should be kept level and permeable and firing should be as rapid and regular as possible. Reference is also made to the mechanism of sintering, variation in permeability during sintering, the mineralogical composition of the sintered ore, and its spongy and slaggy structure.

Flotation of Molybdenite. M. Mortenson. (Tidsskrift för Kjemi, Bergvesen og Metallurgi, 1948, vol. 8, Jan., pp. 5–9) [In Norwegian].

FUEL—PREPARATION, PROPERTIES, AND USES

Air Entrainment in Gas Burners. G. von Elbe and J. Grumer. (Industrial and Engineering Chemistry, 1948, vol. 40, June, pp. 1123–1129). Air entrainment in burners with cylindrical tubes can be calculated on the basis that part of the stream momentum is transformed into static pressure corresponding to the flow resistance imposed by friction, buoyancy, and flame thrust. Satisfactory agreement with experimental data was found. When the flame is to be distributed over a number of port openings, Venturi ducts are required. The energy loss in a Venturi duct was studied by measuring separately the potential energy, the kinetic energy corresponding to average velocity, and the kinetic energy contributed by the velocity profile. It was concluded that the energy contributed by the velocity profile is lost between throat and head in the form of eddy motions.—R. A. R.

Temperature Range in the Combustion Zone. I. E. Kubynin. (Journal of Technical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1415–1420). [In Russian].

Gas Turbine Power for Iron and Steel Works. (Oil Engine, 1947, vol. 15, July, pp. 76–77).

Heat Transfer Symposium. (Industrial and Engineering Chemistry, 1948, vol. 40, June, pp. 1019–1122). A symposium of heat transfer was held at the fourteenth annual meeting of the Division of Industrial and Engineering Chemistry at the Illinois Institute of Technology on December 29 and 30, 1947. Abstracts of the papers follow.—R. A. R.

Fräukl Regenerator Packings. G. Lund and B. F. Dodge. (*Ibid.*, pp. 1019–1032).

Design of Temperature-Measuring Elements. M. T. Cichelli. (*Ibid.*, pp. 1032–1039). *See* p. 101.

Heat Transfer in a Recirculating Furnace. M. J. Sinnott and C. A. Siebert. (*Ibid.*, pp. 1039–1044). The effect of air temperature and air velocity on the rate of heat transfer to steel in a recirculating air furnace was investigated. The value of h_c, the instantaneous convective heat-transfer coefficient, is independent of the temperature difference between metal and air for a given constant air temperature. The values of h_c for various air temperatures and velocities were calculated. These, together with h_c, the instantaneous radiation coefficient of heat transfer, make possible the calculation of the time required to heat a metal to any given temperature in a recirculating air furnace. R. A. R.

Fin Heat Transfer by Geometrical Electrical Analogy. C. F. Kayan. (*Ibid.*, pp. 1044–1049).

Heat Transfer to Granular Materials. M. S. Brinn, S. J. Friedman, F. A. Gluckert, and R. L. Pigford. (*Ibid.*, pp. 1050–1061). Calculations were made of the heat transferred into beds of granular material moving downwards through vertical steam-jacketed tubes, assuming rod-like flow, and the results agreed closely with the conductivities measured using stationary beds. Theoretical equations are developed for the general cases of counter-current

and parallel flow heat-transfer to a material in rod-like flow in a tube.—R. A. R.

Unsteady-State Heat Transfer between Air and Loose Solids. G. O. Löf and R. W. Hawley. (*Ibid.*, pp. 1061–1070). Design data in the form of unsteady-state heat-transfer coefficients from air to a bed of granite gravel are presented and a formula for calculating such coefficients is presented.—R. A. R.

Air Turbulence and Transfer Processes. E. W. Comings, J. T. Clapp, and J. F. Taylor. (*Ibid.*, pp. 1076–1082).

Heat Transfer to Vertical Tubes in a Mixing Vessel. J. H. Rushton, R. S. Lichtmann, and L. H. Mahoney. *Ibid.*, pp. 1082–1087).

Mass and Heat Transfer in Tube Banks. C. C. Winding and A. J. Cheney, jun. (*Ibid.*, pp. 1087–1093).

Radiative and Convective Heat Transfer Rate Pertaining to Heating Processes. J. Huebler. (*Ibid.*, pp. 1094–1098). The author attempts to compare, under theoretically ideal conditions, the effects of radiation and convection heating simultaneously applied to a plate. For this purpose an equivalent "radiation heat transfer coefficient" is utilized, and although the differential equations involved are insoluble, graphical methods of solution are applied. The results reveal the proportions of the heat transferred by convection and radiation.—R. A. R.

Heat Transfer with Extended Surface. W. E. Dunn, jun. and C. F. Bonilla. (*Ibid.*, pp. 1101–1104).

Drying Coal Fines in Centrifugal Driers. (Echo des Mines, 1948, May, pp. 91–92). Centrifugal drying of fines for the manufacture of coke is discussed and the Reineveld drier and its operation described.—R. F. F.

Preparation of Coal for Coke Production. P. E. Jordan. (Iron and Steel Engineer, 1948, vol. 25, May, pp. 56–59). The selective mining, blending, cleaning, and pulverization of coal for coking purposes are considered. The strength of the coke can be increased considerably by changing the degree of pulverization from 60% to 85% through a $\frac{1}{8}$-in. screen. It appears that a minimum stability and hardness are necessary for good results in the blast-furnace, but improvements in these properties above this minimum value become decreasingly beneficial.—R. A. R.

Coal Pyrites for Sulphuric Acid Manufacture. D. T. Davies. (Coke and Gas, 1948, vol. 10, May, pp. 168–172). Descriptions are given of the plant and processes by which pyrites containing an average of 42% of sulphur were recovered from colliery refuse, the production being raised from about 4000 to 35,000 tons/annum.—R. A. R.

Instrumentation in Gasworks and Coke Ovens. R. W. Griffin. (Coke and Gas, 1948, vol. 10, May, pp. 180–184). The importance of efficient instrumentation for the control of gasworks and coke ovens is stressed and the quantities which it is advisable to measure are listed and discussed.

R. A. R.

Thermal Expansion of Coals and Carbonised Coals. D. H. Bangham and Rosalind E. Franklin. (Transactions of the Faraday Society, 1946, vol. 42B, pp. 292–295). In order to avoid the obscuring effects of absorption expansion arising from films on micellar surfaces the specimens were heated in dry nitrogen at, say, 100° C till the shrinkage became negligible; the temperature was then lowered by stages with readings every few degrees and raised again slowly to 100° C, also with readings; it was then raised rapidly to, say, 150° C and the procedure repeated. The silica optical-lever extensometer used is described. Three coals were examined: (*a*) A high-oxygen bituminous coal from which both monoliths and artefacts could be prepared, (*b*) a high-carbon bituminous coal (actually used for coking), yielding only artefacts, and (*c*) an anthracite from which only monoliths, both parallel and normal to the bedding plane could be made. After removal of the effects of abnormal expansion and shrinkage by preheating, (1) the expansion coefficient was practically independent of preheat temperature below 300° C; (2) within each temperature range it was independent of the rank, type of specimen, pressure in making artefacts, and orientation of the monoliths of the bituminous coals; (3) it increased markedly and steadily with temperature; (4) when the bituminous coals were preheated to above 325° (coal (*a*) or 350° C (coal (*b*)), the coefficient of expansion at lower temperatures was diminished; (5) for carbonization temperatures above 550° (coal (*a*)) and 600° C (coal (*b*)) the volume expansion was well below the value for macrocrystalline graphite; (6) the coefficient of linear expansion of the coke produced was lower for coal (*a*) than for coal (*b*); (7) for anthracite the expansion coefficient varied much less with temperature but markedly with orientation.

A. E. C.

Determination of the Wall-Surface Temperature of the Chambers of Coke Ovens and the Characteristics of the Heat-Flow into the Charge. B. I. Kustov and A. I. Voloshin. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 441–445). [In Russian]. An account is given of an investigation, carried out at the Kharkov Experimental Coking Plant, of the thermal conditions in well-regulated Becker and Giprokoks ovens. These ovens were coking a charge with a moisture content of 5–6% in 15–16 hr, a temperature of 1330–1340° C being maintained in the heating flues. A special device was used for the measurement of the surface temperature of the chamber walls, consisting of a suitably insulated steel plate carrying an iron-constantan thermocouple which could be lowered through the charging hole and pressed tightly against the wall. The plate was fixed to a long iron tube in which the thermocouple leads were also situated. In addition to the wall temperature, the temperatures of the centre of the charge and the wall of the heating flue were continuously recorded. The results obtained are presented and are used, in conjunction with a partial heat balance, for the calculation of the thermal flow through the wall and the charge. The value for the thermal conductivity of dinas brick obtained in these calculations is in good agreement with values determined in laboratory experiments.—S. K.

Reactivity of Coke. J. P. Urzola. (Anales Física y Química, 1946, vol. 42, pp. 555–572: British Abstracts, 1948, BI-6, May, col. 185). This is a survey of the literature. It is concluded that the activity of coke increases with decrease in the agglutinating power of the coal, the size of the coke, and the coking temperature and time.

Modern Gas Producers. J. L. Swift. (Ceramic Industry, 1948, vol. 50, Jan., p. 63: [Abstract] British Coal Utilisation Research Association, Monthly Bulletin, 1948, vol. 12, Mar., p. 101). The sizes, outputs (100,000–30,000,000 B.Th.U/hr.) and costs of a range of producers available from Wellman Engineering Co., Cleveland, are stated.

Decentralizing the Production of Energy by Individual Gas Producers. M. Schreckenbach. (Technik, 1948, vol. 3, Apr., pp. 183–184). The construction of large low-temperature gas producers is advocated in Germany not only to produce gaseous fuel, but also to supply much needed chemical by-products.—R. A. R.

The Physical Statistical Fundamentals of Gas Cleaning. F. Magyar. (Radex Rundschau, 1948, Apr., pp. 3–8). Statistical methods of determining the efficiency of electrostatic gas cleaners are explained.—R. A. R.

The Quality of Long-Distance Gas. W. Heischkeil. (Stahl und Eisen, 1948, vol. 68, June 17, pp. 228–230). Fluctuations during recent years in the physical properties and calorific value of long-distance gas from the Ruhr, and their causes are discussed.—R. A. R.

The Application of Fuel Oil and Surplus Gas at an Integrated Iron and Steel Works. J. Sinclair Kerr. (Journal of the Institute of Fuel, 1948, vol. 21, June, pp. 254–258). In this appendix to his paper (*see* Journ. I. and S.I., 1948, vol. 159, July, p. 321) information is given on the use of compressed air for atomization and on the results obtained by oil firing at a 90-ton open-hearth furnace.—R. A. R.

Some Thoughts on the Relationship between Coal and Oil. J. A. Oriel. (Journal of the Institute of Fuel, 1948, vol. 21, June, pp. 246–247). The author examines the economic aspects of the use of coal and oil in Great Britain. It would be advantageous to change from coal to oil burning in cases where using 1 ton of heavy fuel oil would release 2 tons or more of coal for export. The employment of Diesel-electric and direct-drive Diesel locomotives, and the conversion of open-hearth furnaces and soaking pits to oil fuel are advocated.—R. A. R.

TEMPERATURE MEASUREMENT AND CONTROL

The Calibration of a Thermocouple. A. Taylor. (Journal of the Birmingham Metallurgical Society, 1948, vol. 28, June, pp. 85–99). Temperature scales, the gas thermometer, and the measurement of temperature by thermocouples are discussed and the calibration of the platinum/platinum–rhodium thermocouples is described in detail.—R. A. R.

Design of Temperature-Measuring Elements. M. T. Cichelli. (Industrial and Engineering Chemistry, 1948, vol. 40, June, pp. 1032–1039). Methods are presented for determining the distance which thermocouples must extend into a gaseous atmosphere to reduce the error of reading due to conduction of heat along the unit to less than a certain given amount. A number of specimen calculations are given.—R. A. R.

Monitors for Molten Metals. J. Markus. (Scientific American, 1947, vol. 177, Aug., pp. 64–66 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 56). An account is given of temperature regulation of open-hearth furnace flames, heat-treatment furnaces, molten metals, and Bessemer converter flames.

Improving Temperature Compensation of Recording Pyrometers. P. Lincke. (Instruments, 1948, vol. 21, Mar., p. 246).

Thermal Measuring Instruments. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1728 : H.M. Stationery Office). This report covers the design, manufacture, and industrial application of temperature measuring instruments in Germany. The Bioptix colour-brightness pyrometer is widely used in the steelworks and it is described in detail. Particulars of experimental work in progress are also given.—R. A. R.

Automatic Temperature Control. A. M. Adams. (British Coal Utilisation Research Association, Monthly Bulletin, 1948, vol. 12, Mar., pp. 73–93). After outlining the basic elements of a control system, the author compares and classifies different modes of automatic temperature control. A bibliography of 107 references and an appendix on " Theories of Control " are included.—J.C. R.

Temperature Indicating Compounds. G. A. Williams. (Electronic Engineering, 1946, vol. 18, p. 208 : British Ceramic Abstracts, 1948, Mar.–Apr., p. 112A). Temperature-indicating devices described are of two kinds, paints containing a pigment which is formulated to change colour at a given temperature, and compounds which melt sharply at a predetermined temperature, supplied as crayons, emulsions, and pellets. The crayons are available in 13° and 25° intervals from 125°–350° F (52°–177° C), emulsions cover a similar range, and pellets a higher range up to 1800° F (982° C) in 25° and 50° intervals.

Colorimetric Temperature Control. M. de Buccar. (Energie, 1948, vol. 32, May, pp. 127–132). The different types of colour indicators for temperature control, their composition, colour changes, and methods of application, are surveyed. A bibliography of 34 references is appended.—R. F. F.

Determination of Maximum Temperatures in Combustion Chambers and Industrial Furnaces. I. E. Kubynin. (Journal of Technical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1411–1414 [in Russian] : [Abstract], Metals Review, 1948, vol. 21, June, p. 42). Mathematical formulæ are given for the determination of these temperatures. Curves of oxidation and reduction converge at a point located on the boundary between the oxidation and reduction zones where the temperature of combustion reaches its maximum.

Temperature Control of Electrically Heated Gas Carburising Furnaces. (Instrumentation, 1948, vol. 3, No. 2, p. 21) : Ceramic Abstracts, 1948, May 1, p. 109).

Determination of the Temperature in the Region Just Below the Crown of Coke Ovens. B. I. Kustov, A. I. Voloshin, and I. A. Kopeliovitch, (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 1459–1462). [In Russian].

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Largest Blast Furnace in France. (Echo des Mines, 1948, June, pp. 120–121). The characteristics and profile of the blast-furnace which is being rebuilt by the Société des Forges et Aciéries du Nord et de l'Est, are described. It has a hearth diameter of 6·5 m, height from hearth to stockline 24·5 m, and volume 900 cu.m., and the expected daily output will be in the region of 700 tons.—R. F. F.

Determination of the Capacity and Size of Blast Furnaces. D. A. Diomidovskii. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1946, pp. 579–593 : Chemical Abstracts, 1948, vol. 42, Apr. 20, col. 2553). This is a collection of dimensions and operating data on several types of blast-furnaces, together with discussion on the interrelation of some of the significant variables.

The Width of the Annular Combustion Zone in New North American Blast-Furnaces. E. Krebs. (Stahl und Eisen, 1948, vol. 68, June, 17, pp. 237–238). The question of using either the hearth area or the area of the annular combustion zone of a blast-furnace as a basis for computing the specific capacity and coke consumption is discussed, and the method explained by F. Wesemann for determining the width of this zone under different conditions (*see* Journ. I. and S.I., 1948, vol. 159, June, p. 213) is applied to North American blast-furnaces.—R. A. R.

The Action of Regenerators and Cowper Stoves as Heat Accumulators. J. Szczeniowski. (Revue de Métallurgie, Mémoires, 1947, vol. 44, Nov.–Dec., pp. 321–329). The large weight of refractory bricks entering into the construction of regenerators enables them under certain conditions to be used as heat accumulators ; this is particularly so in the special case of the Cowper stove. A governing condition is that the temperature to which the blast is to be heated must be sufficiently removed from the maximum to which the stove can be heated. After outlining the particular interest in heat accumulation in an ironworks (irregular blast-furnace working, hence irregular gas supplies, mechanical and electrical breakdowns, differences of working load at different parts of the plant, etc.), the author enumerates the conditions to be satisfied by a Cowper stove if it is to act as a good " buffer," and then makes a theoretical study of the thermal conditions and phenomena during the accumulation of heat. Reference is made to zoned stoves, the object of which is to make the absorption of heat more uniform throughout the appliance. The practical operation of " accumulation " and the use of " mixed blast " (cold air mixed in suitable proportions to bring the temperatures of the air leaving the accumulator down to the steady figure required) are described, and the upper and lower limits of practical heat accumulation are indicated.—A. E. C.

Trends in Pig-Iron Manufacture. T. P. Colclough and I. S. Scott-Maxwell. (Journal of The Iron and Steel Institute, 1948, vol. 159, June, pp. 186–192).

Study of Acid Smelting in French Steelworks. M. Chenet. (Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1948, vol. 5, Mar. 25, pp. 137–151). Acid working in French blast-furnaces has not proved as successful as expected. To ascertain the reason for this, a detailed account is given of tests carried out at Caen, Senelle, Denain, and Neuves Maisons, particular attention being paid to the basicity of the slag. All the tests were made with blast-furnaces designed for basic operation, the temperature of the blast varied from 650° to 800° C, and there was no special preparation of the charge. In none of the cases was the anticipated improvement obtained. The reasons for the success of acid working at Corby and at the Appleby-Frodingham works at Scunthorpe are outlined. The following conclusions are reached : Whilst the addition of MgO increases the fluidity of the slag, acid working is only advantageous with proper preparation of the charge ; the open-hearth furnaces must be prepared to accept iron with a higher silicon content than normal ; tests are necessary to determine the best operating conditions for a charge of a defined composition ; at some works the descent of the charge has been regular but at others difficulties have arisen ; the temperature in the hearth should be kept constant to obtain a sufficiently fluid slag and an iron with a constant silicon content ; variation in the chemical composition of the charge affects the temperature in the hearth.—J. C. R.

Smelting under Pressure. L. Engel. (Scientific American, 1948, vol. 178, May, pp. 54–57). The operation of a blast-furnace at high top pressures is discussed.

Effect of Coke Quality on Blast Furnace Iron Tonnage. E. J. Gardner. (American Iron and Steel Institute, 1948, Preprint : Blast Furnace and Steel Plant, 1948, vol. 36, June, pp. 707–711). The Inland Steel Company recently carbonized selected blends of coal under identical conditions of coke-oven operation and used the coke in successive tests in the same blast-furnace, also under approximately uniform conditions, so as to determine the effect of coke quality on the quantity of the iron produced. In general, when the blend consisted of miscellaneous low and high volatile coals with large variations in expansion characteristics and a higher ash content, the coke was larger in size and not so hard, and this lowered the blast-furnace efficiency. Introducing weathered Pocahontas coal

produced coke with too much breeze, and in the blast-furnace this caused a decrease in the wind blown and the iron produced.—R. A. R.

Blast Furnace Smelting of Titanium Magnetite Ores to Yield Basic Slags. I. V. Shmanenkov and K. Kh. Tagirov. (Bulletin de l'Académie des Sciences de l'U.R.S.S., Classe des Sciences Techniques, 1947, pp. 391–397: Chemical Abstracts, 1948, vol. 42, June 20, col. 4119). Basic iron titanium (calcium, magnesium, aluminium) silicate ore containing up to 13% TiO_2 is smelted by the addition to the melt of miaskite, nepheline-egerinite, or other basic mineral to yield slags containing up to 15–20% TiO_2 and with a CaO/SiO_2 ratio of up to 1·4. This method also ensures more complete reduction of the vanadium present, only 10% is lost in the slag. Such TiO_2 slags act as good desulphurizers in the Bessemer process using Donetz cokes. Detailed data on the temperatures of the melt, and the chemical compositions of the ores, fluxes, cokes, iron, flue gases, and the slag are shown.

Qualitative Characteristics of Bakal Siderites and Their Use as Raw Material for the Production of Pig Iron. L. M. Tsylev. (Bulletin de l'Academie des Sciences de l'U.R.S.S., Classe des Sciences Techniques, 1947, pp. 399–407). Many of the siderite ores of the Bakal deposits are characterized by the admixture of high magnesium basic rocks with the ratio $\Sigma (CaO + MgO)/\Sigma (SiO_2 + Al_2O_3) = 4 \cdot 5$. These siderite deposits vary greatly and contain 29–35% iron and only $\frac{1}{5}$ to $\frac{1}{3}$ as much phosphorus (0·01%) as do the adjacent brown iron ores, but ten times as much silicon (0·27%). The siderite ores are reduced readily at 700°. When these ores are mixed with an equal amount of brown iron and reduced by a Kuznetsk coke of low sulphur content, a good quality of iron can be obtained. The fuel requirement is 0·82 tons per ton of pig iron obtained. A diagram shows the iron-ore reserves of Bakal for the various grades of iron ores.

Utilization of Roasted Pyrites and Red Mud in Pig Iron Production. B. Stirling. (Bányászati és Kohászati Lapok, 1948, vol. 81, May 15, pp. 135–141). [In Hungarian]. Shortage of iron ore in Hungary during the war brought about the utilization of roasted pyrites for pig-iron production. As about 50,000 tons of pyrites are processed by the sulphur and cellulose industry per year the utilization of 40,000 tons of iron containing residues is important for increasing the efficiency of those industries. Including the iron content of the available 100,000 tons of red mud, a total of 51,000 tons of pig iron can be obtained yearly from these two waste materials. Roasted pyrites were pressed into briquettes and used for pig iron production during the war. Towards the end of the war, when binding materials were scarce, the material was used in agglomerated form; this proved to be an advantage, as it was more porous and about 20% less coke was required for the reduction process. Iron is produced in rotary cylindrical furnaces either by methods where the metal and slag are not liquefied, or by methods where liquid metal and slag are obtained. Of the first-mentioned methods the Krupp-Renn process has proved to be the most satisfactory; the Stülzberg process is the most successful of the methods producing liquid metal and slag. Both methods present several advantages. Inferior pulverized coal or even gas can be used as fuel, and pulverized coke or soft coal are usable for the reduction; the charge need not be broken up into small pieces and it is not necessary to eliminate harmful admixtures before charging the roasted pyrites into the furnace. Moreover, the zinc and lead content is not lost but can be recovered from the escaping vapours. The iron obtained is of good quality and can be directly utilized in open-hearth or electric furnaces. The Krupp-Renn process is carried out in a furnace 3·6 m in dia, 50 m long, and furnaces used in the cement industry are suitable for the purposes. The output is 250–300 tons/day and pulverized roasted pyrites can be used without it being necessary first to agglomerate the material. About 90–95% of the iron content is extracted and the iron produced has an iron content of 97% to 98%. Correct fuel feed is essential for good operation of the process to obtain the required temperatures in the individual zones of the furnace, which must not be exceeded. Admixtures which are harmful in blast-furnaces are harmless here, because they evaporate and escape with the gases. The Stülzberg process is carried out in a dolomite-lined furnace 11·5 m long and 3·8 m in dia. The roasted pyrites need no pretreatment; in the case of red mud there is an additional advantage in that the titanium oxide gets into the slag. The usefulness of this process has been adequately proved as good quality pig iron has been obtained from raw materials with high contents of zinc, sulphur, and other elements. Pulverized coal or gas is used for fuel and pulverized coke for the reduction process. The reducing part of the furnace is swivel-mounted, the liquid metal being discharged and the recharging effected in the swivelled position. Ten tons of roasted pyrites require 3·5 tons of coke for reduction with 2·5–6 tons for fuel and 2–6 tons of quicklime for slag formation. The slag obtained contains 57% of CaO and 27% of SiO_2 and it is suitable for cement production. The output is 17–20 tons/day of pig iron; this is very pure and is used for special purposes, like Swedish charcoal iron. Charging and heating up take 1·5–2 hr, zinc elimination and partial iron-reduction 4 hr, iron-reduction and slag formation, 30 min. The use of electric furnaces has also been considered, but cheap power is required for such furnaces; moreover, the ore has to be broken up into small pieces, and zinc and antimony have an unfavourable effect on the reduction process. The utilization of pyrites and red mud for pig iron production was discontinued after the war and the author thinks that it would be advantageous for Hungarian economy to start using these materials again for pig iron production.—E. G.

Results of Experiments on Extraction of Iron from Bauxite Which Were Carried Out in 1938 and 1939 in Petafurdo (Hungary). B. Selmeczi. (Bányászati és Kohászati Lapok, 1948, vol. 6, June, pp. 169–175). [In Hungarian]. The objects of the experiments were to develop a suitable process for extracting the iron from bauxite, which would also produce a calcium aluminate slag suitable for processing into cement; to use Hungarian coke for production of pig iron of low sulphur content; and to test the use of oxygen-enriched air for the furnace blast. Oxygen was available on the spot, as it was obtained as a secondary product in ammonia production. The air enrichment was increased up to 30% oxygen and experimental operation lasting a month showed that this cold oxygen-enriched air is capable of replacing preheated air in blast-furnace processes. The blast-furnace gases contained CO_2 4–6%, hydrogen 4–6%, and CO 38–40%. The average composition of the bauxite was 48–49% of Al_2O_3, 25–26% of Fe_2O_3, 3·2% of TiO_2, 2·5–4% of SiO_2, 6–8% of moisture, and 12–13% ignition losses. Owing to the small furnace dimensions, but mainly because unsuitable coke was used, the bottom part of the furnace solidified and it became necessary to tap the pig iron and the slag from the same hole and separate them outside the furnace. By using a more suitable coke the solidification stopped and the pig iron could be tapped from the bottom hole. The analysis of the pig iron obtained was Fe 94·49%, S 0·01%, Ti 0·6%, P 0·5%, Mn 0·1%, Si 0·3%, and C 4%. The slag produced a good quality cement with excellent mechanical properties. Increasing the oxygen in the blast above 30% did not prove satisfactory, the resistance increased and it was necessary to reduce the blast volume, and solidification set in. The experiments showed that Hungarian bauxite can easily be utilized for pig iron production and that the calcium aluminate slag after grinding makes a very good quality cement. The economic problem is to utilize the large quantities of the cement produced by this process, because the present production of Portland cement fully satisfies the requirements of Hungary. The relative slag quantities can be considerably reduced by adding other materials with a high iron content to the bauxite charge. The pig iron obtained is suitable for use as hematite iron or for castings. The individual experiments are described in detail and the relevant data compiled in tables.—E. G.

A Shaft Furnace for Smelting Lean Iron Ores. W. Kuczewski. (Hutnik, 1947, vol. 15, July–Aug., pp. 343–347). [In Polish]. This paper describes a type of furnace in which the ore and fuel are charged in a fine state; the thermal characteristics and the quality of the gas are also discussed.—W. J. W.

Demolition of Blast-Furnace Linings and Hearths. (Iron and Coal Trades Review, 1948, vol. 157, July 2, pp. 15–17). This article describes the use of explosives both for the removal of salamander from the hearth bottom and for the breaking up of scaffolds and the brickwork of the stack. Ammon gelignite or blasting gelatine are recommended, in sheathed cartridges. Pneumatic drills are used on brickwork and the

oxygen lance for the harder materials impregnated with metal.—J. P. S.

PRODUCTION OF STEEL

Future Sources of Iron Units in Scrap. C. R. Holton. (American Iron and Steel Institute, 1948, Preprint: Blast Furnace and Steel Plant, 1948, vol. 36, June, pp. 697–700). The situation of the supply of steel scrap in the United States is reviewed. It is estimated that 25 million tons of scrap per annum will be required for some time to come. Scrap from the railways and the ship-breaking yards has increased in quantity, but the demand will continue to be very great and measures to obtain scrap from Germany and Japan are advocated.

Weirton Steel Company. T. J. Ess. (Iron and Steel Engineer, 1948, vol. 25, May, pp. 16-w–34-w). An illustrated description is given of the integrated iron and steel works of the Weirton Steel Company on the Ohio River.—R. A. R.

Dutch Report on Different Subjects in the Steel and Metal Industry. (British Intelligence Objectives Sub-Committee, 1948, Miscellaneous Report No. 79: H.M. Stationery Office). Reports on visits to eighteen German firms are presented; they give brief accounts of many metallurgical processes connected with the manufacture of steel and non-ferrous metals.—R. A. R.

Steel. How Made and How Much. C. A. Scarlott. (Westinghouse Engineering, 1948, vol. 8, No. 3, pp. 66–74: Chemical Abstracts, 1948, vol. 42, June 20, col. 4110). This is a review of modern practice. Electric steel amounts to 4% of U.S. total steel production. The average arc-furnace production is 25–30 tons/heat.

The Application of Vacuum in Metallurgy. L. Colombier. (Revue de Métallurgie, Mémoires, 1947, vol. 44, Nov.–Dec., pp. 374–379). The application of a vacuum to molten metal may cause a displacement of the equilibria of chemical reactions involving gaseous or volatile constituents and it may also simply remove physically any gases or volatile substances in the steel. Concerning the first effect, the author discusses the influence of reduced pressure on the decarburizing and deoxidizing reactions in steelmaking. The pressures need not be very low to have any effect. Heats of several tons of steel can now be melted under a vacuum. With regard to the evacuation of gases, the pressure must be reduced to an extremely low value, so that, while vacuum methods of gas analysis are used in the laboratory, the degassing of metals on an industrial scale presents difficulties due to gases absorbed in refractories, the volume of which is too great to be pumped off satisfactorily. A third use of a vacuum is as a neutral atmosphere under which certain alloys may be more satisfactorily prepared; thus chromium–molybdenum alloys for turbine blades are extremely brittle if melted in air, but much less so if melted *in vacuo*. Yet another application is the evacuation of all the gases from moulds before casting, in order that the metal shall take more exactly the finest details of the mould.—A. E. C.

Steelmaking in Acid Side Blown Converters. N. F. Dufty. (Blast Furnace and Steel Plant, 1948, vol. 36, June, pp. 683–690, 751). Steelmaking practice at the works of K. and L. Steelfounders and Engineers, Ltd., Letchworth, is described and a theory for the reactions is offered. Two cupolas charged with steel scrap 80% and iron 20% are used alternately and the metal is desulphurized in the ladle with sodium carbonate. This metal is blown in 2½-ton side-blown converters. The physical chemistry of the reactions during the blow are discussed.—R. A. R.

The Use of Blown Metal in Open Hearth Steelmaking. H. B. Emerick. (American Institute of Mining and Metallurgical Engineers: Blast Furnace and Steel Plant, 1948, vol. 36, June, pp. 695–696). Problems in the blowing of hot metal in the converter and subsequent refining in the open-hearth furnace are considered. A silicon/manganese ratio of 2·5 min gives good elimination of silicon in the converter. If this ratio is high, up to 2% of CaO may be tolerated in the converter slag. As little as 150 lb of blast-furnace slag in the converter may be detrimental to blowing. The use of oxygen-enriched air in the latter stages of the blow is suggested to reduce the nitrogen content.—R. A. R.

Refractory Problems in Connection with the Use of Oxygen in Heavy Iron Processes. S. V. Glebov. (Kislorod, 1946, No. 2–3, p. 18: British Ceramic Abstracts, 1948, Mar.–Apr., p. 132A). The refractory lining of the walls of an acid converter is affected by the action of acid slag formed during conversion. The bottom plate and the tuyeres, being exposed to iron and manganese oxides for considerable periods, swiftly corrode. When high-silicon iron is being melted, a crust often forms on the walls. When oxygen is used, crust is therefore less likely to be formed. Other factors will be the same as in the acid process, but with temperature conditions higher by 100°–150° C. In the converter, the refractory lining has to stand a temperature of about 1800° C for about 5–10 min. On completion of the melt, when the metal is removed, the temperature of the lining falls sharply to 1250–1300° C or lower, but when melting is recommenced it rises again in 10–15 min to 1800° C. Various special refractories are described, and there is a report of unsuccessful experiments carried out on fourteen types of tuyeres, all of which were of no further use after one melt. A general discussion follows on the necessity for organizing intensified research into special refractory materials. In the blast-furnace process, oxygen raises the temperature in the neighbourhood of the tuyeres 200–300° C above the usual, and makes the blast-furnace more suitable for melting ferrous alloys and aluminous slags. In these circumstances the lining of the blast-furnace around the bosh and the hearth is exposed to the action of refractory slag with high lime or alumina content, and a melting temperature above 1500° C. In the hearth the temperature is 100°–150° C higher than usual, while in the stack it is lower and the gases contain less nitrogen and up to 45% of carbon dioxide.

The Use of Oxygen in the Open-Hearth Process. C. Schwarz. (Radex Rundschau, 1947, Oct., pp. 35–49). Results obtained by adding pure oxygen to coke-oven gas and to oil for firing open-hearth furnaces are critically examined and a theoretical investigation of the replacement of preheated air with cold oxygen is made, the theoretical results being compared with full-scale plant data. Its use is very advantageous for the cold-charge process, and for the scrap–carbon process in countries where coke is scarce.

Direct Oxidation in the Basic Open Hearth Process. E. B. Hughes and F. G. Norris. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2380: Metals Technology, 1948, vol. 15, June). The rate of carbon elimination in 160-ton basic open-hearth furnaces when oxygen was blown into the bath through a ¾-in tube at about 500 cu.ft./min was investigated. To reduce the carbon content of 1 ton of steel in the bath from 1·00% to 0·90% requires 1–2 cu.ft. of oxygen for each 0·01%; to reduce it from 0·25% to 0·10% requires 3–3·5 cu.ft.; from 0·10% to 0·05% requires about 15 cu.ft.; and below 0·05% 40 to 60 cu.ft. are required for each 0·01%. Compared with indirect oxidation of the carbon with ore, the benefits of direct oxidation are most pronounced with carbon below 0·08%. It is possible entirely to replace charging ore by blowing oxygen. No evidence was obtained that the use of oxygen affected the rate of removal of sulphur, although there may be an indirect improvement due to the increase in agitation of the bath.—R. A. R.

Boiling of Liquid Metal in the Bath of a Steel-Melting Furnace. V. S. Kocho. (Journal of Technical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1527–1530). [In Russian].

The Cooling of Basic-Lined Open-Hearth Furnaces. F. Bartu. (Radex Rundschau, 1947, June, pp. 24–28). The advantages and disadvantages of the cooling systems for open-hearth burner parts are explained and the differences in the systems for silica and Radex ports are shown. Data and calculations on the effect of cooling on production and fuel consumption are shown, Finally, the increased use of the heated water for central heating is advocated.—R. A. R.

Experience with Cold-Gas-Heated Open-Hearth Furnaces with Gas Supplied by Two Different Coke-Oven Plants. F. Keller. (Stahl und Eisen, 1948, vol. 68, June 17, pp. 230–231). Statistics are presented which show how the melting time and heat consumption per ton of steel for a 40-ton open-hearth furnace decreased when the gas supply was changed from one coke-oven plant to another with a deterioration in quality of the gas.—R. A. R.

The Existence of a Critical Point in Refining Steel. F. Castagneli. (Metallurgia Italiana, 1947, vol. 39, pp. 119–125: Chemical Abstracts, 1948, vol. 42, May 20, col. 3296). A series of complete analyses was made of the components of melts in the process of refining steel. There is a critical point which divides the process of refining into two parts. First there is a progressive deoxidation due to the carbon

present and secondly a progressive oxidation due to low carbon content. Thus there is a point of minimum oxygen content of the melt which has been shown to depend on the rate of deoxidation and the rate of increase in temperature of the steel melt during the refining process.

High-Alloy Steels with Nitrogen Additions. H. Schottky. (Zeitschrift für Metallkunde, 1948, vol. 39, Apr., pp. 120–122). German and Austrian investigations of the use of nitrogen in high-alloy steels to reduce the required amount of nickel are reviewed. Nitrogen can be added by charging nitrogen-enriched ferrochromium but the nitrogen/chromium ratio must not exceed 1/75, and the normal ferromanganese and ferrochromium additions must be made first and be given time to be taken up by the bath. Additions of 0·1% to 0·3% of nitrogen can be made to austenitic chromium–manganese steels.—R. A. R.

Kinetics of the Transfer of Sulphur Across a Slag-Metal Interface. Lo-Ching Chang and K. M. Goldman. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2367: Metals Technology, 1948, vol. 15, June). The rate of migration of sulphur across the slag-metal interface was studied using charges of Armco iron, ferrous sulphide, and slags in a graphite crucible in an induction furnace. Takings K_S as the coefficient of transfer of sulphur from slag to metal and K_m as that for metal to slag, the data obtained showed that K_S does not change appreciably with changes in slag composition, whilst K_m increases very rapidly with increasing basicity of the slag. K_m is more sensitive to temperature than K_S; the latter is increased by about 6% and the former by about 12% for a rise in temperature of 10° C. The calculated energy of activation for the transfer of sulphur from slag to metal is 39,000 cal/mol and for metal to slag 79,000 cal/mol.—R. A. R.

The Rapid Determination of the Basicity of Open-Hearth Slags with the Aid of Their Paragenesis. F. Trojer. (Radex Rundschau, 1948, Apr., pp. 27–32). The principal ternary systems occurring in open-hearth slags are described, and full details are given of the mineralogical and chemical compositions and appearance, with micrographs of nine slags ranging in basicity from 51·9 to 74·0. It is shown that samples of molten slag can be chilled and specimens prepared for examination under the microscope with transmitted and reflected light in a few minutes. By comparison of samples with the nine standards, the basicity can be determined with sufficient accuracy and speed for controlling the open-hearth process. The method is a modification of that of R. Tenenbaum and T. L. Joseph (*see* Journ. I. and S.I., 1941, No. II, p. 119A).—R. A. R.

Duplexing Steel Operation Affords Greater Use of Stainless Scrap in Melt. D. Reebel. (Steel, 1948, vol. 122, June 28, pp. 90, 93, 108). A brief description of an induction-furnace/arc-furnace duplex process for producing stainless steel ingots for tube making is given. The advantage of the process is that up to 60% stainless steel scrap can be charged; the light scrap is charged in the arc furnace and the heavy scrap into the 2·5-ton high-frequency furnace. A high degree of chromium recovery is achieved.—R. A. R.

Advancement in the Construction of Electric Arc Furnaces. L. Hütter. (Radex Rundschau, 1948, Apr., pp. 15–26). Improvements to electric-arc furnace linings are discussed and the designs for several types of furnace roof are described. R. A. R.

The Choice of an Electric Melting Furnace. A. Trovati. (Ingegnere, 1946, vol. 20, Feb., pp. 82–84 [in Italian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 1/2, p. 240).

Ordinary High-Frequency Melting Furnaces. A. R. Baffrey. (Charleroi-Jeumont, 1947, Jan.–June, pp. 1–13: [Abstract] Mécanique Documentation, 1948, vol. 3, May, p. 5).

Percentage Losses in High-Frequency Furnaces as Compared with Arc Furnaces. C. Ciamberlini. (Ingegnere, 1946, vol. 20, Aug., p. 616 [in Italian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 1/2, p. 90). Melting of chromium, tungsten, molybdenum, and vanadium steels in an arc furnace is accompanied by appreciable losses in the alloying metals due to volatilization of the metals or their oxides. These losses are eliminated when high-frequency furnaces are used instead of arc furnaces.

Practices Affecting Yields and Surface Qualities of Rimmed and Semi-Rimmed Steels. L. R. Silliman. (American Institute of Mining and Metallurgical Engineers: Blast Furnace and Steel Plant, 1948, vol. 36, May, pp. 550–554; June, pp. 691–694). The author has studied ladle, mould, and heating practices in rimmed 0·06–0·22% carbon steels, and semi-killed 0·12–0·50% carbon steels, cast from 120- and 220-ton furnaces in 23 × 25-in moulds; the rimmed ingots weighed 5·3 tons, the semi-killed, 6·0 tons. He found that, in the case of rimmed steel the use of $NaF–Fe_3O_4–Al$ mould additions reduced rise in the mould giving higher yield and better surface quality, close control of pouring temperature to 1580° C max increased the number of ingots not requiring surface treatment by 27%, controlling the FeO content of the slag between 17% and 22% produced small yield increases, and good mould coatings increased the number of ingots not requiring surface treatment by 29% in steels low in sulphur, and by 31% in those high in sulphur. In the case of semi-rimmed steels, he found that proper ladle deoxidation with silicon is necessary so that mould deoxidation with aluminium can produce the desirable crowned top, that pouring at temperatures above 1580° C increased yield loss due to piping or checked tops to 1·2% and decreased the tonnage not requiring conditioning by 11·0%; delays in charging ingots into soaking pits increased the amount of piping by 1·8% in the case of good and by 2·4% in the case of bad ingot practice, and decreased the tonnage not requiring conditioning by 12% for high-sulphur and 20% for low-sulphur grades. "Washing" or sealing in the soaking pit gave a loss of 2·4% on ingots made with good practice, 2·6% on under-deoxidized ingots, and 3·7% on over-deoxidized ingots. Poor mould coatings on semi-killed steels low in sulphur produced a 5% decrease in the tonnage not requiring conditioning.—J. P. S.

Respective Advantages and Disadvantages of Round and Square Ingots in the Manufacture of Special Steels. R. Scherer. (Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1948, vol. 5, Feb. 25, pp. 61–63). It is simpler and more economic to eliminate defects in ingots before they are rolled into billets. This is done by turning, and the advantages of round ingots for this purpose are apparent. With round ingots solidification conditions are more uniform and crystallization tends to be more regular, but there is a tendency towards the formation of longitudinal cracks unless the steel is deoxidized and great care is exercised in controlling the temperature and rate of cooling. Round ingots are less easy to handle because of the risk of sliding and methods for avoiding this disadvantage are outlined. Reference is made to practice at Deutsche Edelstahlwerke at Krefeld, where most of the ingots produced are round.—J. C. R.

FOUNDRY PRACTICE

A Review of Progress in Gray Irons. J. H. Schaum. (Foundry, 1948, vol. 76, June, pp. 98–101, 240–250). In a study of the year's progress, the author picks out, among other things, the developments in immersion pyrometers, the work of J. E. Rehder on the influence of silicon, H. Morrogh on the influence of tellurium, and F. E. Rose and C. H. Lorig on the effect of minor elements such as aluminium, antimony, arsenic, beryllium and bismuth, introduced from copper alloy scrap; the most important research effort of 1947 was, he considers, that of H. Morrogh on nodular graphite. The Laplanche diagram produced during the year is an improvement over the Maurer diagram and relates microstructure more accurately to carbon content. In the moulding field he comments on the high-carbon/resin bonding material known as Westonite, and on the "C" process, which produces a bakelite sand shell which is backed with steel shot or sand. In the field of equipment, he comments on Piwowarski's new cupola designs, and on the slagging gas-producers operating in France.—J. P. S.

Gray Cast Iron. Some Principles Involved in Heat Treatment. A. Boyles. (American Foundryman, 1948, vol. 13, Mar., pp. 97–106). The author reviews the fundamental principles involved in the heat-treatment of grey cast iron, pointing out the differences between this and steel. Because of its higher carbon and silicon contents, grey iron exhibits both the stable (iron plus graphite) and metastable (iron plus cementite) states, and the transformations therefore involve both these. The presence of silicon brings into existence a new zone on the equilibrium diagram where α- and γ-iron and iron carbide are in metastable equilibrium and a similar one where α- and γ-iron and graphite are in stable equilibrium. Transformations through these zones are of great interest, and the behaviour

of the matrix in relation to the state of the carbon provides grounds for the differences of response to heat-treatment between cast iron and steels.—J. P. S.

Magnesium Equipment for an Iron Foundry. A. J. Marotta. (Modern Metals, 1948, vol. 4, May, pp. 26–27). The experience of an American foundry making radiators and other small iron castings using core plates, vent boards, and flasks made of magnesium is reported. Extra ribs and generous fillets must be provided in magnesium equipment to prevent distortion by heat. In spite of spilling and run-outs no magnesium flask has been burnt, but two bottom boards did catch fire during pouring. The light weight of magnesium equipment reduces fatigues and the cost of handling.

R. A. R.

Cupola Operations Improved with Oxygen-Enriched Blast. W. C. Wick. (American Foundryman, 1948, vol. 13, May, pp. 64–74). A number of trials in a 19-in cupola with oxygen-enriched blast indicate that with 10% oxygen added to the normal blast volume, and an 8/1 coke ratio, (1) the melting rate is increased by 20% ; (2) the tapping temperature is raised 55° C ; (3) there is a more fluid slag and less bridging ; (4) by control of oxygen content and total blast volume, with a given coke ratio, tapping temperature and melting rate can be controlled ; tapping temperature may also be controlled by adjusting the coke ratio. It is possible to obtain the same operating conditions with a 12 : 1 iron/coke ratio with the use of 8–9% oxygen as with a 5 : 1 iron/coke ratio without it. By proper manipulation of the oxygen supply it is possible to avoid increased wear of refractories ; moreover, there is less oxidation loss of the silicon in the charge. The author also comments on the advantages of periodic additions of oxygen in producing hot iron at short notice, and in supplying extra heat to remove bridging or overcome other temporary operating difficulties.—J. P. S.

Oxygen and Cupola Operation. A. W. Gregg. (Foundry, 1948, vol. 76, June, pp. 86–90). Experiments by the Armour Research Foundation in a small experimental cupola, using added oxygen up to 13·8% of the blast volume, suggest that by this means melting rate can be increased to 30% above the normal, while the oxidation losses of metalloids and the over-all melting losses are reduced. Lining wear is increased, owing more than anything to the increase in temperature. About 10% oxygen seems to be the limit ; above this it seems to have a detrimental effect.—J. P. S.

Metallurgical Coke of Y.P.F. Tests of Cupola Melting to Determine its Service Behaviour. A. R. Gray. (Laboratoria de Ensayo Materiales e Investigationes Technologicas, Buenos Aires, 1947, Series II, No. 17 : Chemical Abstracts, 1948, vol. 42, June 20, col. 4332).

Nodular Graphite Structures Produced in Gray Cast Irons. H. Morrogh. (American Foundryman, 1948, vol. 13, Apr., pp. 91–106). *See* Journ. I. and S.I., 1948, vol. 158, Mar., pp. 306–322.

Belgian Foundry Produces Wear-Resistant Cast Iron. G. Halbart. (American Foundryman, 1948, vol. 13, Apr., pp. 140–141). Les Fonderies Magotteaux at Vaux-Les-Liége produces grinding balls and cubes in a nickel alloy white cast iron.—J. P. S.

Unusual Structures Observed in Gray Cast Irons of High Sulphur Content. J. E. Rehder. (American Foundryman, 1948, vol. 13, May, pp. 91–93). The inadvertent addition of a quantity of iron pyrites containing 25% of sulphur to a cupola producing grey iron had a remarkable effect. The sulphur content rose from 0·12% to 0·41%, the total carbon fell from 3·50% to 3·13% and the manganese from 0·60% to 0·37%, castings had a white chilled rim, and the microstructure showed that no pearlite was present in either the white or grey portions. The matrix was, however, ferrite, not austenite ; a considerable number of inclusions of a duplex FeS–MnS were present. On annealing a sample, pearlite was produced and the duplex inclusions converted to normal MnS. A second accidental addition of pyrites produced an iron of 0·27% sulphur, also lower in total carbon and manganese than the normal iron. The microstructure was, however, normal, except for the presence of a lot of MnS inclusions. It was, nevertheless, extremely hard to cut, but no explanation for this was found.—J. P. S.

Slag Control is Important in Cupola Operation. (American Foundryman 1948, vol. 13, May, pp. 109–110). One of the most important characteristics of a cupola slag is a low viscosity, which gives good combustion conditions, permits proper air distribution, allows carbon pick-up to take place, and free flow from the slag hole. Basic oxidizing slags containing 35–45% of silica seem to be the most valuable. Increased volume over that normally produced by the charge is also an advantage ; this may be produced by the addition of silica sand, siliceous rock, or a crushed cupola lining material.—J. P. S.

Casting is Changing. E. L. Cady. (Scientific American, 1947, vol. 177, Aug., pp. 67–69 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 46). Reference is made to new techniques and new alloys, and the production of high-quality castings where forging was previously necessary.

Hard and Semi-Hard Rolls. S. Maj and Z. Wusatowski. (Hutnik, 1947, vol. 14, Nov., pp. 519–533). [In Polish]. This discusses the types of cast iron suitable for chilled and semi-chilled rolls with details of the appropriate chemical composition and casting technique. The existing literature on the hardness of rolls is fully considered.—W. J. W.

Large Scale Production of Miscellaneous Castings in High-Duty Grey Iron. (Nickel Bulletin, 1948, vol. 21, May, pp. 62–65). Modern practice for the production of cast iron is discussed and the "constant charge" system of cupola operation as used for the production of grey iron castings at the foundries of Messrs. Lloyds (Burton) Ltd., and John Fowler & Co. (Leeds), Ltd., are briefly described.—R. F. F.

Vitamins for Iron. (Inco, 1948, vol. 22, Spring Issue, pp. 22–23 : [Abstract] Metals Review, 1948, vol. 21, May, p. 6). An account is given of the inoculation of grey-iron castings with "Nisiloy," a product containing approximately 60% of nickel, 30% of silicon and 10% of iron, to improve machinability and achieve other beneficial results.

The Production of Ni-Hard Cast Iron. W. W. Braidwood. (Fonderie Belge, 1947, No. 12, pp. 5–20).

A Cause of Poor Anneability of a Commercial Malleable Iron. J. E. Rehder. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Apr., pp. 20–21). An investigation was carried out to determine the reason why certain heats of iron did not respond satisfactorily to annealing treatment The probable cause was the presence of 0·09% of tin which was considered sufficient to stabilize the cementite in the pearlite. Lead and antimony were also present indicating that the tin was probably introduced in the form of white metal in the scrap.—M. A. V.

Elimination of Anneal for Light Gray Iron Castings. R. G. McElwee. (Vancoram Review, 1948, vol. 5, No. 3, p. 19 : [Abstract] Metals Review, 1948, vol. 21, May, p. 34). The use of a graphitizing type of inoculant is described. The addition of a prescribed amount will serve to eliminate the chilled edge by causing the casting to graphitize to gray iron uniformly throughout the mould. The cost of treatment is claimed to be only a small fraction of the cost of annealing. The casting quality should also be better because of the uniformity of structure, which reduces shrinkage and casting stresses.

Fom a Sandman's Notebook. H. E. Henderson. (Western Machinery and Steel World, 1948, vol. 39, Apr., pp. 98–99).

Valuable Properties Found in Western Bentonites. E. C. Troy. (American Foundryman, 1948, vol. 13, May, pp. 111–112). Examination of samples of bentonites show that, in spite of the producers' guarantees of uniformity in a variety of physical properties and *p*H value, differences exist in wetting properties which affect green strength, dry strength, and deformation.—J. P. S.

Graphical Representation of the Grain Distribution in Moulding Sand. E. O. Lissell. (Gjuteriet, 1948, vol. 38, Mar., pp. 43–52). [In Swedish]. The results of screen analyses of moulding sands can be presented in several ways, *viz.*,: (1) By transfering to each of a row of test tubes the sand retained on each sieve in the A.F.A. (American Foundrymen's Association) set of sieves ; (2) by direct or relative frequency curves ; and (3) by direct or logarithmic summation curves. Method (1) is incorrect. The best picture is obtained with the relative frequency curve, whilst the summation curve is recommended for comparing a large number of screen analyses. A standard diagram for logarithmic plots which can be applied to both American and German sets of sieves is presented.

R. A. R.

Controlling Sand Grain Distribution Reduces Steel Foundry Costs. C. A. Sanders. (American Foundryman, 1948, vol. 13, Apr., pp. 142–146). To reduce metal penetration, and scabs due to the expansion of sand in casting the author advocates the use of sands of a more uniform grain distribution, and the use of wood flour in conjunction with cereal binders. Bentonite for rebonding used sands should be sprayed on in the form of a slurry as the sand leaves the shake out.—J. P. S.

Preparing Foundry Sand with Manganese Resinate. F. Fere. (American Foundryman, 1948, vol. 13, Apr., pp. 147–149). Manganese and lead resinates, prepared by melting natural resins with MnO_2 and/or PbO_2 when mixed with siccative linseed oil in the preparation of oil-sand cores. promote rapid drying and hardening throughout the mass of the core. Less finishing of cores and moulds is required, and accuracy is greater.—J. P. S.

Does Metal Vapour Cause Sand Penetration? S. G. Jones. (American Foundryman, 1948, vol. 13, Apr., p. 139). The writer enumerates several phenomena in steel castings which lead him to the opinion that metal penetration in sand moulds may be due to the condensation of metal vapours or metal-laden gases emerging from the metal after solidification.

The "Lennox" Sand-Drier. (Foundry Trade Journal, 1948, vol. 84, June 10, pp. 563–564). A description is given of a non-rotary hot-air drier for foundry sand. Its advantages are : (1) No large rotating parts ; (2) requires small floor area ; (3) extreme simplicity, is easily handled by unskilled labour ; (4) delivery of cooled dry sand up to 100 ft from the "wet" sand intake ; (5) high thermal efficiency ; (6) low maintenance costs ; (7) continuous operation ; and (8) adaptable for use with most heating media.—R. A. R.

Design of Pouring Gates by Application of Hydraulic Calculations. J. Kieswetter. (Hutnické Listy, 1948, vol. 6, June, pp. 165–170). [In Czech]. Casting is basically a hydraulic process and application of hydraulic analysis to the design of pouring gates can considerably reduce the number of defective castings. The well-known basic equations of flow continuity ($Q = F.c$), the relation between the potential and kinetic energy ($c^2/2g = H$), and the static pressure of a liquid column ($p = \gamma H$) are applied for investigation of the flow of molten metal. Viscosity and high surface tension prevent penetration of the molten metal through the pores of the mould, but air and gases penetrate into the mould and gases are also generated inside it as a result of combustion. Suitable flow formation can prevent absorption of air and gas by the molten metal. It is essential to prevent subatmospheric pressure to eliminate suction of air and gases through the porous mould, and turbulence should also be avoided to prevent erosion of moulding sand. With laminar flow a "skin" is formed on the wall surfaces and the flow speed in the boundary layers is very low. Laminar flow exists if the Reynolds number is below 2500, *e.g.*, a flow in a cross-section 40 mm in dia would be turbulent, but it would be laminar if 18 cross-sections each 10 mm in dia were used. A stream of liquid flowing from an opening in the bottom of a vessel does not necessarily disintegrate, and, owing to speed increase, a contraction of the cross-section occurs, which is given by the equation $F = Q/\sqrt{2gH}$ (neglecting friction losses). In a complex system the speed is calculated for the smallest cross-section and the appropriate equation is given. The common types of pouring gates are analysed to determine the conditions required for elimination of subatmospheric pressures throughout the stream of molten metal. The results of calculations were confirmed experimentally by a test arrangement with water and manometers. A water column proportional to the subatmospheric pressure at the test points was observed, and air, admitted to the test points by opening cocks, was drawn into the main stream ; air bubbles were observed escaping from the bottom of the test tube. The results obtained are applicable to molten metal, as the viscosity of molten pig iron at 1400° C is $\nu_1 = 0{\cdot}28 \times 10^{-6}$ sq.m./sec, and that of water at 20° C is $\nu_V = 1{\cdot}01 \times 10^{-6}$ sq.m./sec. The surface tensions differ greatly and water adheres to the walls of the tube, but molten metal does not. It is very advantageous to interrupt the continuity of the vertical stream to obtain a second level of the liquid as the pressure diagrams obtained are more favourable. The calculations described need to be confirmed by further tests and suitable casting experiments.—E. G.

Gating System Designs Affect Pouring Rates. J. G. Mezoff and H. C. Elliott. (American Foundryman, 1948, vol. 13, Apr., pp. 107–112). Work was undertaken, using magnesium alloys, to determine which factors in a gating system control the pouring rate of castings. It was found : (1) Pouring rate does not increase linearly with increased cross-sectional area of an untapered round sprue, owing probably to increased turbulence, but does increase roughly linearly with depth of metal in the pouring basin and to an extent greater than that due to increased depth when the mouth of the sprue is "belled-out." (2) Sprue length does not affect the pouring rate of untapered round sprues. (3) There is a maximum temperature for a given sprue for maximum pouring rate. In tapered round sprues, resistance to flow is offered by the side-walls, and the effect of head in the pouring basin is not so pronounced. In slot sprues it is found that conditions similar to those obtaining in round untapered sprues occur, but that the side-wall resistance enters in, resulting in lower rates of flow for the same cross-section.—J. P. S.

Feeding Castings. A New Approach. S. T. Jazwinski. (American Foundryman, 1948, vol. 13, May, pp. 75–80). Experiments are described and illustrated to show the beneficial effect of suspending a gas-forming material in the feeder head of steel castings which, by adding a gas pressure to the gravity head, promotes adequate feeding. The gas-forming material is enclosed in a heat-resisting coating which delays reaction for a short time, and a refractory non-return valve prevents the gas blowing back up the runner.—J. P. S.

Designing Strainer Cores. H. L. Campbell. (American Foundryman, 1948, vol. 13, May, pp. 107–108). Seven standard shapes and sizes of strainer cores are proposed, to control discharge from pouring basins and the flow of metal in gating systems.—J. P. S.

Ethyl Silicate as a Bonding Agent in Mouldmaking. A. E. L. Jervis. (Plastics (London), 1947, vol. 11, pp. 358–360 ; Chemical Abstracts, 1948, vol. 42, May 20, col. 3295). Moulds for metal-casting at temperatures up to 1600° are made by the lost-wax process from sillimanite and $Si(OEt)_4$.

Practical Aspects of Machine Moulding. J. H. Peers. (Institute of British Foundrymen : Foundry Trade Journal, 1948, vol. 84, May 27, pp. 507–510). The operation and applications of various machines used in moulding are described, including sandslingers, jolt roll-over machines, jolt squeeze roll-over machines, strippers, pneumatic jolt squeezes, and core blowers. Control and production planning are discussed.

Westinghouse Is Operating an Automatic Molding Unit. J. A. Sharrits. (Foundry, 1948, vol. 76, June, pp. 78–84, 216–222). To produce several million end-brackets for fractional horse-power motors in grey cast iron, Westinghouse Electric Corp., Cleveland, Ohio, uses a simplified multiple moulding system ; steel flasks are used with five patterns per flask, stacked six high. The moulding is fully automatic, and all other operations are fully mechanized.—J. P. S.

Factors Influencing Core Baking. E. C. Troy. (Foundry, 1948, vol. 76, June, pp. 92–95, 252–256). The complete baking of oil-sand cores is difficult and requires good and well-maintained ovens. Cores should be baked until their centres have reached a temperature sufficient to ensure the continuance of the oxidation reaction in the open air. The hollowing out of core centres and the filling of the space with sand or cinders is advised.—J. P. S.

Producing Ingot Moulds in India. Some Experiences of a General Foundryman. V. McGowan. (Iron and Coal Trades Review, 1948, vol. 156, May 28, pp. 1108–1110). The author describes the manufacture of cores and moulds for ingot moulds weighing 3½ tons each at a steelworks in India. An iron of the following analysis is used : C (total) 3·2% ; C (graphitic) 2·9% ; Si 1·7–1·8% ; Mn 0·68–0·75% ; P 0·28–0·32% ; S 0·07–0·08% ; this is poured at 1220° C, and very satisfactory castings are produced. The average life of a mould including "stickers" and overpoured moulds is 66·23 casts.—J. P. S.

Flywheel for Brazil. (Western Machinery and Steel World, 1948, vol. 39, Apr., p. 89).

Giant Castings for Grand Coulée. (Western Machinery and Steel World, 1948, vol. 39, Apr., pp. 82–85).

Simplified Methods and Improved Equipment Advances Precision Investment Casting. K. J. Yonker. (Steel, 1948, vol. 122, June 7, pp. 96–99). This paper describes precision

casting on a large scale by the lost-wax process with considerably mechanized methods at the works of Allis-Chalmers Manufacturing Co., Milwaukee.—J. P. S.

How to Make Precision Castings. J. Van Voast. (American Machinist, 1947, vol. 91, June 19, pp. 125–140).

Centrifugal and Precision Steel Castings for Aircraft. J. F. B. Jackson. (Engineering, 1948, vol. 165, May 21, pp. 481–484). The principles of centrifugal casting and the applications for which horizontal-axis and vertical-axis casting are most suitable are explained. The moulding methods adopted at the steelfoundry of Messrs. David Brown and Sons (Huddersfield), Ltd., for the centrifugal casting of chromium–molybdenum and nickel–chromium–molybdenum high-tensile steels for aircraft parts are described in detail. R. A. R.

The Foundry of Tomorrow Today. C. B. Dick. (Scientific American, 1947, vol. 177, Dec., pp. 252–254: [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 16). Increased mechanization of plant and improved lighting and cleanliness helps to speed up production and improve the quality of the product.

New Alloy Foundry Typifies Modern Design. P. Dwyer. (Foundry, 1948, vol. 76, June, pp. 104–108, 270–274). A new plant has been erected for the American Shoe Co., at Elyria, Ohio. A battery of six electric furnaces with capacities of from 200 to 10,000 lb is employed for melting a variety of alloy steels, such as a 19/9 chromium–nickel steel, and Ni-Resist cast irons, such as Type 1 containing C 2·75–3·10%, Si 1·0–2·0%, Ni 13–15%, Cu 5–7%, Cr 1·25–4·0%, and Mn 1·0–1·5%. Heat-treatment and inspection, which includes X-ray and Zyglo crack detection, are as fully mechanized as possible.—R. A. R.

Centre Technique des Industries de la Fonderie. J. Drachman. (Gjuteriet, 1948, vol. 38, Apr., pp. 59–60). A short account is given of the organization and programme of the Centre Technique des Industries de la Fonderie, Paris, which was founded in 1941.—R. A. R.

Brazilian Foundry Produces Chilled Car Wheels. M. M. Siqueira. (American Foundryman, 1948, vol. 13, Apr., pp. 150–152). Car wheels, vacuum-brake cylinders, and miscellaneous castings are produced at São Paulo, Brazil, from charcoal pig iron of indigenous manufacture.—J. P. S.

Proposed Standards for Cast Iron Flasks, Flask Pins, and Bushings. (Gjuteriet, 1948, vol. 38, Apr., pp. 61–67). The recommendations of the Flask Standardization Committee of Mekanförbundet are reported.—R. A. R.

Control of Gray Iron Casting Defects. W. B. McFerrin. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Apr., pp. 17–19, 34–35, 39). The 30 basic casting defects listed by the American Foundrymen's Association Committee on Analysis of Casting Defects are enumerated. Possible causes of the main types of defect are given in detail.—M. A. V.

Foundry Production Control. W. A. Turner and A. K. Jeffrey. (Institute of British Foundrymen : Foundry Trade Journal, 1948, vol. 84, June 3, pp. 529–535 ; June 24, pp. 613–619). Details are given of efficient methods of organization, layout, and flow of material in an ironfoundry.

The Roller Conveyor in the Foundry. M. Stap. (Metalen, 1948, vol. 2, June, pp. 222–225). [In Dutch]. The roller conveyor system at the foundry of N.V. Vulcanus, at Vaassen, is described.—R. A. R.

Suggested Research into the Causes of Ingot-Surface Defects. H. O. Howson. (Iron and Coal Trades Review, 1948, vol. 156, June 18, p. 1297). The liability of ingots to surface defects is influenced by the initial skin of crystals formed during the teeming process, and the ferrostatic pressure. Little fundamental knowledge is available on this problem, and a method of obtaining data on the strength and ductility of steel at temperatures near the solidus is proposed. A rotating mould, say 1 ft in dia × 1 ft long, could be supplied from a high-frequency furnace, and controlled centrifugal force could be substituted for ferrostatic pressure.—R. A. R.

Grinding Standards Help Eliminate Cleaning Room Bottlenecks. D. Van Order. (American Foundryman, 1948, vol. 13, Apr., pp. 125–129). The application of time study to grinding operations, and the establishment of standard procedures, can save time and money.—J. P. S.

HEATING FURNACES AND SOAKING PITS

Modern Ingot and Billet Reheating Furnaces. P. Beuchon. (Métallurgie, 1948, vol. 80, June, pp. 15–19). After discussing the thermal aspects of reheating furnaces, the author examines various kinds of soaking pits, pusher-type furnaces, burners, and recuperators.—J. C. R.

Economical Operation of Town or Coke-Oven-Gas-Fired Furnaces. J. Molinié. (Energie, 1948, vol. 32, Mar., pp. 55–60). The choice, construction, and operation of gas-fired furnaces are studied from the point of view of thermal efficiency. R. F. F.

Heat Losses in Furnace Linings. J. D. MacCullough. (Petroleum Refiner, 1947, vol. 26, July, pp. 112–117 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 3/4, p. 624). Simple and rapid methods for the determination of heat losses are outlined.

Vacuum Furnace for Induction Heating. R. Kiessling. (Jernkontorets Annaler, 1948, vol. 132, No. 7, pp. 237–242). [In Swedish]. A high-frequency vacuum induction furnace for laboratory use is described. The source of energy is a Philips generator with an output of 5 kW and a frequency of 800 kilocycles/sec. The furnace consists of a silica tube evacuated with a mercury-vapour pump. A set of different silica tubes is available and radiation screens of Al_2O_3 or "pytax" may be inserted. The pressure on the high-vacuum side is measured with a Pirani gauge. Examples of different applications are described.—R. A. R.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Progress in the Heat Treatment of Steel. E. S. Davenport. (Scientific American, 1948, vol. 178, Apr., pp. 148–153).

Heat Treatment of Metals. M. Sourdillon. (France Energétique, 1947, Sept.–Oct., pp. 133–139 : [Abstract] Revue Universelle des Mines, 1948, Series 9, vol. 4, July, p. 426).

Control of Heat Treatment. A. H. Koch. (Industrial Heating, 1948, vol. 15, Jan., pp. 66–74, 113, Mar., pp. 416–420, 532–534 ; Apr., pp. 580–588, 712–714). In Part I the author stresses the importance of controlling temperature and time of heating, and describes batch, rotary, chain, and belt types of furnace. In Part II the discussion of heat-treatment furnaces is completed ; roller-hearth, shaker-hearth, and walking-beam furnaces are considered. Surface protection by controlled atmospheres or salt baths is discussed, and the use of radiant tube and indirect-fired bell-type furnaces described. In Part III modern developments in the theory and practice of controlled atmospheres and generators for these atmospheres are dealt with. Finally, recommendations on the design of quenching equipment are made.—R. A. R.

Oxidation and Decarburization on Heating and Rolling. G. Wallquist. (Jernkontorets Annaler, 1948, vol. 132, No. 5, pp. 123–169 ; No. 6, pp. 175–212). [In Swedish]. The theory of oxidation and decarburization of steel is examined, previous investigations on a laboratory scale are reviewed and a report is presented of new laboratory and full-scale tests. The literature on the influence of steel composition, gas composition and velocity, and reheating time and temperature on oxidation and decarburization is reviewed (42 references). Polished specimens 10 mm in dia of 12 steels were used in new investigations ; these included seven carbon steels (C 0·10% to 0·97%), three low-alloy chromium–nickel steels, and two high-alloy stainless steels. These were exposed in a stream of gas composed of 80% of nitrogen and 20% of CO and CO_2, the CO/CO_2 ratio was varied between 6 and 0. The gas velocity and reheating temperature and time were also varied. The results confirmed that the degrees of oxidation and decarburization depend mainly on the reheating temperature and time. In full-scale operation changes in gas composition and velocity have only a limited effect. Full-scale tests were made on 0·74% and 0·82% carbon steels at five steelworks during the rolling of ingots to 75 × 75 mm billets, and in rolling the latter to 22-mm rounds. Some billets were rolled without surface treatment, others were partly pickled, and others ground quite clean. Decarburization was studied on bars after different passes. The average decarburization was of the same magnitude in the different works. Decarburization of ground billets was much less than for untreated billets. Decarburization of billets and bars was irregular and of varying depth in different pieces as well as along the surface of the same billet or bar ; it changed in degree as rolling proceeded. It may increase or decrease at the same point on the surface. Certain parts of the surface

may be quite free from decarburization and at other parts it may be severe; this is due to variations in the flow of material at the surface in relation to the centre; this flow is most pronounced with severe reductions and with uneven reduction across the width of the bar.—R. A. R.

Salts for Heat Treatment. E. Hague. (Metallurgia, 1948, vol. 38, May, pp. 39–43). This paper describes the use of "neutral" salts for hardening and annealing, cyanide mixtures for carburizing, sodium hydride for descaling, sodium hydroxide for de-enamelling, and a special salt for liquid nitriding. J. P. S.

Sub-Zero Treatments for Carburized Medium-Alloy Parts. J. C. Selby and E. S. Rowland. (Metal Progress, 1948, vol. 53, May, pp. 667–671). Experimental work on seven alloy carburizing steels, in the range C 0·1–0·2%; Cr 0·15–1·5%; Ni 0·5–5·0%; and Mo 0·0%–0·26%, was carried out to determine if subzero treatment after carburization would reduce the retained austenite content of the case as well as, or better than, the conventional double treatment. It was found that though some significant hardness may be produced there are no advantages to be gained from sub-zero treatment, the product being neither better than, nor different from, that obtained by double quenching, and, in the case of products ground after carburizing, the expense is unwarranted; however, if it is necessary to avoid the distortion introduced by the double-quenching process, subzero treatment, which does so, may be useful for medium-alloy steels.—J. P. S.

Cold Treatment and Assembly of Metallic Parts. G. Bolson. (Machine Moderne, 1947, June, pp. 1–6: [Abstract] Revue Universelle des Mines, 1948, Series 9, vol. 4, May, pp. 356–357). Subzero temperatures have the following applications: (1) Dimensional stabilization and hardening (−100° for some hours and annealing at 150–180°); (2) recovery of gauges, etc.—of faulty dimensions and hardness—cold-treatment transforms residual austenite into martensite with dilatation and increase in hardness; (3) artificial ageing, especially of aluminium alloys; (4) refrigeration of cutting tools causing 50–500% gain in the life of the tool (5); improvement in tempering of high-speed steels through the elimination of residual austenite giving increased hardness and elasticity; (6) improvement of hardened steels in general, usually due to the removal of residual austenite and unannealed martensite; and (7) avoidance of cracks during grinding or reheating.

Some Recent Heat Treatment Furnace Installations. (Metallurgia, 1948, vol. 38, May, pp. 50–57). Gas-carburizing plants made by Birlec, Ltd., and the Leeds and Northrup Company, Efco-Hultgren salt-baths, G.W.B. Electric Furnaces Ltd.'s light-alloy slab pre-heating furnaces, Siemens Schuckert pit-annealing furnaces for light-alloy castings and forgings, British Furnaces Ltd.'s tempering furnaces for springs, and some miscellaneous furnaces for heat-treatment in tool rooms and repair shops are described.—J. P. S.

Make Your Furnace-Design Specifications Work for You. N. J. Connors. (Power, 1948, vol. 92, May, pp. 102–104).

Utilization of Recrystallization and Grain-Size Enlargement for Improvement of Quality of Transformer Steels. F. P. Rybalko and M. V. Yakutovich. (Journal of Technical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1503–1512). [In Russian].

Other Applications of Electric Furnaces. V. E. Rasmussen. (Elektroteknikeren, 1947, vol. 43, Dec. 7–22, pp. 534–543 [in Danish]: Electrical Engineering Abstracts, 1948, vol. 51, Apr., p. 104). Types of furnaces used in the ceramic industry are described and the advantages of electric furnaces, ease of regulation, economy, cleanliness, and small size, are emphasized. Applications to baking and drying, including infra-red, are dealt with, and arc furnaces for steel manufacture and induction furnaces for heat-treatment are described. A sketch is given of the Brown-Boveri rotating-magnet eddy-current generator.

Synthetic Atmospheres in Electric Hardening Furnaces. (Smit Mededelingen, 1947, vol. 2, Oct.–Dec., pp. 93–101).

Induction Hardening of Cold Rolls. G. W. Seulen and H. Kuhlbars. (Iron and Coal Trades Review, 1948, vol. 156, June 4, pp. 1159–1164, 1187). A description is given of the equipment used for the induction hardening of rolls used for cold rolling sheet and strip. For rolls up to 8 in in dia and 12 in long a coil enclosing the whole face can be used, but "feed hardening," in which the coil followed by the water spray is moved over the roll, is employed for larger rolls. The rolls are rotated during the heating and quenching. For a roll body 7 in in dia and 8 in long a current density of 1·2 kW/sq.in. is required, the heating time being 11 min for 0·6 in depth of hardness. Frequencies in the 600–3000 cycles/sec range are sufficient for the process. Examples of fractures of hardened surfaces and micrographs of the surface transition zone, and core of a hardened roll are shown. R. A. R.

Use of Town Gas for Heat Treatment Furnaces. M. A. de Jerphanion. (France Energétique, 1947, Sept.–Oct., pp. 140–144: [Abstract] Revue Universelle des Mines, 1948, Series 9, vol. 4, July, p. 426).

FORGING, STAMPING, DRAWING, AND PRESSING

Research and Development in the Mechanical Working and Surface Treatment of Steel. T. Bishop. (Iron and Coal Trades Review, 1948, vol. 156, May 21, pp. 1041–1054). The research activities of the Mechanical Working Division of the British Iron and Steel Research Association are described.—M. A. V.

Modern Trends in Hot Forging Operations. C. W. Hinman. (Steel Processing, 1948, vol. 34, May, pp. 256–258). New, high-speed forging machines built by the National Machinery Co., Tiffin, Ohio, are described, with illustrations of the products.—J. P. S.

Statistical Analysis for Quality Control of Forgings. E. W. Mace. (Steel Processing, 1948, vol. 34, Apr., pp. 193–197; May, pp. 248–250, 258). A statistical analysis of tests on forgings was made primarily to determine permissible tolerances, but also to obtain information on the effects of operating factors such as depth of die, die wear, the human element, performance of different machines, and machine maintenance and wear. Data are given for a drop-forged steel connecting rod, a flanged steel hexagon nut, formed in a horizontal forging machine and cold sized, and a steel thrust washer. It is concluded that statistical quality control provides a method by which a comprehensive analysis of the factors affecting the size of the component may be undertaken.

Development of Low Weight Forgings. J. H. Friedman. (Steel Processing, 1948, vol. 34, Apr., pp. 183–190, 192). Improved methods of making a variety of small forgings, with low wastage of material, are described.—M. A. V.

Dies for Drawing Complex Shapes. C. R. Cory. (Machinery, 1948, vol. 72, June 24, pp. 755–761). Examples of dies for pressing parts requiring a two-way punch action or more than one drawing operation are described.—R. A. R.

Increased Forging Die Life. H. Chase. (Iron Age, 1948, vol. 161, May 27, pp. 88–94). The sequence of processes in the forging of connecting rods and other automobile parts at a shop operating seventeen steam hammers and three upsetters is described. In some cases scale is removed from the dies by a jet of steam and in others by oil. Copperplating of dies for lubrication was unsatisfactory because it was difficult to control the thickness, but a suspension of colloidal graphite in water increased die life considerably.—R. A. R.

Hobbed Cavities for Metals and Plastics. T. A. Dickinson. (Modern Industrial Press, 1947, vol. 9, pp. 46–48: [Abstract] PERA Bulletin, 1948, vol. 1, May, p. 401). Hobbing is a comparatively recent process of making moulds or cavities of soft steel blanks by forcing a hardened tool-steel pattern at high pressure into the blank, so that it accepts the contour of the pattern. The process has been developed by the Reinhold Geiger Compression Moulding Plant, Los Angeles, for the purpose of reducing tooling costs where several plastic or die-casting moulds are required of the same pattern. The inventors of the hobbing process claim that except where the design of the pattern or the blank material (which in some cases may have to be of high strength and specially heat-resistant) is unsuitable, the process possesses considerable advantages. The author recommends a number of mould materials and gives a detailed description of the operation.

Kirksite Dies for Auto Stampings. W. C. Patton. (Iron Age, 1948, vol. 161, Apr. 15, pp. 78–81). The technique for making dies out of Kirksite, which can be poured at 840° F, for motor-car pressings is described.—R. A. R.

Forging Die Design. J. Mueller. (Steel Processing, 1948, vol. 34, Mar., pp. 137–140). The Bradley upright helve forging hammer is described, and its advantages for certain classes of work and the dies used with it are discussed.—R. A. R.

Forging Die Design—Locked Dies. J. Mueller. (Steel Processing, 1948, vol. 34, May, pp. 242–244). Counter-locking of forging dies reduces wear on dies and hammer guides, but is costly; better balance of die impressions is advised.—J. P. S.

Smaller Valves Using Drop-Forged Components Accommodate Higher Temperatures and Pressures. D. Reebel. (Steel, 1948, vol. 122, Apr. 26, pp. 104–107). The manufacture of iron, steel, and bronze valves up to 600 lb in weight, by the Ohio Injector Co., Wadsworth, Ohio, is described. Methods referred to include sand-casting, drop-forging, and machining from stock. Valves are hydraulically tested before despatch. J. P. S.

Progressive Dies. R. J. Harris. (Steel, 1948, vol. 122, June 28, pp. 78–80, 104). Practical recommendations on the use of progressive dies for the high-speed production of stampings are made. The new Brandes press is described and illustrated. R. A. R.

Precision Forgings. F. P. Peters. (Scientific American, 1947, vol. 176, Mar., pp. 105–107: [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Feb., p. 18). In the operation described forging is first carried out at 1090° C and then at 650°–730° C and it is stated that the results obtained depend largely on the die. An indication is given of the kinds of steel suitable for the method of forging.

Chemical Coatings for Improving the Cold Deformation of Steel. W. Overath. (Stahl und Eisen, 1948, vol. 68, June 17, pp. 231–235). The manner in which chemical coatings, in particular metal phosphates, improve the cold-pressing and deforming of steel is discussed. The physical-chemical behaviour of a phosphate coating in relation to oil and other lubricants is explained. Attempts to produce a phosphate coating on high-alloy corrosion-resistant steels by the electro-deposition of iron with subsequent phosphatizing, and by electrolytic phosphatizing, have not been successful. R. A. R.

The Effect of Friction on the Change of Shape of Forgings. I. Y. Tarnovsky. (Vestnik Inzhenerov i Tehnikov, 1946, No. 9/10. pp. 291–295: [Abridged Translation] Engineers' Digest (London), 1948, vol. 9, pp. 106–108).

Lubrication in Drawing. T. Waterfall. (Machinery Lloyd, 1948, vol. 20, Feb. 28, pp. 103–105: [Abstract] PERA Bulletin, 1948, vol. 1, May, p. 397). Some basic considerations of drawing are briefly given: the deployment of the forces involved, the requirements of a lubricant, causes of material fracture and the comparative testing of lubricants. Recommendations are included in the use of oxides, stearic acid film, soap, and surface pretreatment lubricants. Soap lubricant for brass drawing and mixtures for brass pickling are specified. Solid constituents such as graphite flakes or powdered soap in an oil vehicle have been found to minimize power consumption. Notes on lubrication in drawing steel, especially by the wet-drawing process, and aluminium-drawing lubricants, are made.

The Requirements of Lubricants in Deep Drawing and the Removal of Residues. P. D. Liddiard. (Institute of Vitreous Enamellers: Sheet Metal Industries, 1948, vol. 25, June, pp. 1167–1173). The theories of friction and boundary lubrication and the special requirements for deep-drawing lubricants are explained. There appears to be a more definite reaction between the metal and fatty acids in oils than occurs with plain mineral oils. The presence of a metallic soap is essential for deep-drawing lubrication. Free sulphur in oil causes oxide formation on iron surfaces, but with a metallic soap present the sulphide is formed instead which improves the lubrication. High-pressure additives do not function at low temperatures. Solid additives and soft metallic films are also discussed. A comprehensive table gives methods of removing lubricant residues and decomposition products. R. A. R.

Reed Roller Bit Co. Streamlines Forging Department. G. E. Stedman. (Modern Industrial Press, 1948, vol. 10, Apr., pp. 28, 30, 34).

Symposium on Chain Making. (Journal of the Birmingham Metallurgical Society, 1948, vol. 28, June, pp. 128–152). This Symposium, organized by the Midland Metallurgical Societies, was held at Birmingham on January 22, 1948. Abstracts of the papers follow.—R. A. R.

Chains. P. Jump. (*Ibid.*, pp. 128–132). The requirements, design, manufacture, testing, and heat-treatment of wrought iron short-link chain are briefly described. R. A. R.

Modern Flash Butt Welded Steel Chain Cable. E. Wood. (*Ibid.*, pp. 133–136). A brief description is given of the manufacture of flash-butt-welded steel stud-link chain cable.—R. A. R.

Chains. J. G. Hopcraft. (*Ibid.*, pp. 137–141). The manufacture of small ($\frac{3}{16}$ to $\frac{3}{4}$-in) steel chain by the slow butt-welding process is described.—R. A. R.

Chain. N. I. Bond-Williams. (*Ibid.*, pp. 142–146). Brief accounts are given of the methods of making Jack chain, Chandelier chain, and Victor or Tenso chain. Jack chain is well known as a cheap open-joint link chain for applications not requiring great strength; it is made by a fairly simple wire-forming operation. The initial material for Chandelier chain is strip metal from which pierced blanks are cut; these then pass into an assembling machine; a great variety of link shapes can be produced by variations in the design of the blank. Victor chain has knotted links and the machines for making it have many motions provided by combinations of cams, cranks, and racks and pinions.—R. A. R.

Making a Mining Drill. L. Sanderson. (Mine and Quarry Engineering, 1948, vol. 14, July, pp. 217–219). The sequence of processes in the manufacture of a mining drill is described. R. A. R.

How Conversion to Other Materials Solved Malleable Castings Shortage. H. Chase. (Materials and Methods, 1948, vol. 27, May, pp. 89–92). The International Harvester Company has found that a number of parts previously made as malleable castings can be produced as forgings or stampings; in many cases, lower costs per piece offset tooling costs. J. P. S.

Fabricating Stainless Steel Equipment. H. Seymour. (Petroleum, 1947, vol. 10, Apr., pp. 85–86).

High-Temperature Disk-Forging Developments for Aircraft Gas Turbines. L. B. Fonda. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Jan., pp. 1–12). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 271.—R. A. R.

Hydraulic Presses. J. T. Lewis. (British Engineering Export Journal, 1948, vol. 30, May, pp. 1607–1615). Progress in the design of equipment for hot-working metals is recorded by illustrated descriptions of hydraulic die-forging presses, extruding presses, piercers, accumulators, and pumps.—R. A. R.

Largest Mechanical Press Stamps 32-Feet Rails. J. K. Ferguson. (Steel Processing, 1948, vol. 34, Apr., pp. 191–192). The press described is of 3000 tons' capacity, and it can shape steel stock up to $\frac{1}{2}$ in thick. It has a multiple disc air-operated friction clutch with electric push-button control and an air-operated flywheel brake.—M. A. V.

Electrical Applications in the Wire Industry. J. G. Roby. (Wire and Wire Products, 1948, vol. 23, Mar., pp. 213–220, 265). The following types of wire-drawing machines and their electrical drives are described and discussed: (1) Single block, group driven; (2) single block, individually driven; (3) multiple block with single-motor drive; and (4) multiple block with each block motorized.

MACHINERY FOR IRON AND STEEL PLANT

Trends in the Design and Application of Lifting Magnets. J. D. Leitch. (Iron and Steel Engineer, 1948, vol. 25, May, pp. 78–91). The principles of the design of lifting magnets are explained, old and new designs are compared, and a new welded type, which permits a flatter coil to be used with good dissipation of heat, is described. Examples of a wide range of applications of lifting magnets are illustrated. R. A. R.

Shunting Locomotives for Iron and Steel Works. E. L. Diamond. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 1, pp. 137–141). *See* Journ. I. and S.I., 1947, vol. 156, Feb., p. 309.

Locomotives for Iron and Steel Works. E. L. Diamond. (Journal of The Iron and Steel Institute, 1948, vol. 158, May, pp. 37–59).

Overhead Carrier System. (Steel, 1948, vol. 122, Apr. 19, pp. 92–93). This describes the overhead rail system and weighing mechanism used in the wire storehouse of the Wire Rope Division of the Jones and Laughlin Steel Corporation. All manual lifting of coils within the plant has been eliminated. J. P. S.

Raw Materials Handling in Steelworks Storage Yard. F. C. Wier. (Steel, 1948, vol. 122, Mar. 29, pp. 101–112). *See* Journ. I. and S.I., 1948, vol. 158, Jan., p. 159.

LUBRICANTS AND LUBRICATION

Grease Lubrication—The Swelling of Soaps in Non-Aqueous Liquids. E. W. J. Mardles and E. B. Clarke. (Transactions of the Faraday Society, 1946, vol. 42B, pp. 295–301). An investigation of the swelling of various soaps in organic liquids at temperatures up to 120° C, using a sedimentation-of-powder method, is described. With the swelling data, contact angles and adhesion tensions (Freundlich) are included. The effects of small additions of water, oleic acid, glycerol, etc., to the soap systems, and also the behaviour of soaps in mixed liquids, were likewise studied.—A. E. C.

How to Maintain and Recondition Lubricants in Metal-working Plants. E. L. H. Bastian. (Steel, 1948, vol. 122, May 24, pp. 90–92, 114, 116). The use of a "modified lubricant" having both cleansing and lubricating properties, is advocated for cleaning and flushing. Reconditioning by gravity settling is not completely efficient, and a mechanical or adsorbent mineral filter is preferred; the choice of filter depends upon whether straight mineral or additive type oils are used. Additions may be removed by filtration, and their removal is accelerated by increased oil temperatures. Other methods are centrifuging, and magnetic separation of ferrous particles. Soluble oil coolants are not generally reclaimed, but in grinding service they may be run through strainers and settling tanks, or centrifuged and mechanically filtered. M. A. V.

Automatic Lubrication of Steel Plate and Sheet Machinery. F. A. Westbrook. (Steel Processing, 1948, vol. 34, May, pp. 261–263). The automatic lubrication systems provided on a plate-bending roll, a heavy bending press, a squaring shear, a roller leveller, a press brake, and a high-speed stamping machine are briefly described.—J. P. S.

Latest Lubrication Developments Applied to World's Fastest Cold Strip Mill. (Steel, 1948, vol. 122, Mar. 29, pp. 86–89). Brief particulars are given of the oil and grease lubrication systems for the bearings of the high-speed 5-stand continuous wide-strip mills of the Jones and Laughlin Steel Corporation.—R. A. R.

WELDING AND FLAME-CUTTING

Modern Lime-Coated Ferritic and Deep-Penetration Electrodes. P. Sjöman. (Svařování, 1948, vol. 3, Apr., pp. 38–45). [In Czech]. Modern Swedish electrodes are described, particularly those with basic coatings. To reduce generation of fluorine, pulverized iron is added to the coating material; this has the additional advantage of increasing the quantity of the molten metal and increasing welding speeds by about 20%. Alloying elements are added to the electrode core if large quantities are required, and to the coating if the required alloying quantities are small. If A.C. is used, the transformer should have a minimum no-load voltage of 70 V to obtain good stability of the welding arc. Basic-coated electrodes give a quieter and more stable arc than those with a neutral coating; the weld dimensions are smaller, and the weld metal mixes with a smaller quantity of the parent metal. This is advantageous, particularly if the welded material is high in sulphur. The mechanical properties of the weld material are exceptionally good, and tensile strength, elastic limit, notch-toughness values for a number of samples, and also the chemical compositions are given. Notch-toughness of electrodes with basic coatings is about twice as high as the corresponding values for electrodes with neutral coatings, and the welds made with basic-coated electrodes do not contain slag inclusions. Deep-penetration electrodes of the types used in Britain and U.S.A. are not popular in Sweden; they prefer electrodes of smaller diameter and a thick coating of suitable composition. This is so designed that a very deep crater is formed during welding and the arc voltage is increased to approximately double the value of the arc voltage with other types of electrodes. The crater also stabilizes the arc. These electrodes are suitable for welding carbon steels with tensile strengths between 50,000 and 70,000 lb/sq.in. Cracks may occur in steels with too high carbon contents. Welding can only be carried out in a horizontal position and the welding speed can be twice as high as in the case of standard types of electrodes.—E. G.

Electrodes of High Efficiency for Manual Arc Welding. A. M. Gofner, V. I. Kuznetsov, M. I. Kunis, and N. N. Kryukovskii. (Avtogennoe Delo, 1947, Nov., pp. 21–23 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, May, p. 48). Powdered steel as a component of electrode coatings increases the efficiency considerably. The preparation method is similar to those commonly used.

Welding Electrodes and the Basis for Judging Them. E. Magnusson. (Dansk Teknisk Tidsskrift, 1948, vol. 72, Mar., pp. 37–40; Apr., pp. 57–60; May, pp. 73–77). [In Danish].

Maintenance with Stainless Electrodes. J. A. Cunningham. (Welding Engineer, 1948, vol. 33, Feb., pp. 40–43: [Abstract] PERA Bulletin, 1948, vol. 1, May, p. 447). The advantages of using stainless steel as metal-to-metal hard-facing electrodes and as a basic electrode for rebuilding worn parts are discussed, and numerous examples of its applications are given. Because of its high yield strength and low coefficient of friction it is an excellent material for rebuilding power parts such as driving sprockets, idlers, clutches, and gears. Stainless deposits will work-harden 50 to 100 Brinell points and their wearing qualities are in some cases equal to those of manganese steel. Stainless steel will fuse well with most types of ferrous alloys including manganese steel, high-carbon steel, alloy tool steel, and cast iron. Since it welds with a low amperage, $\frac{1}{16}$-in electrodes can frequently be used and $\frac{1}{4}$-in electrodes are generally suitable.

The Responsibility of the Welder for His Work. R. Nije. (Lastechniek, 1948, vol. 14, May, pp. 55–61). [In Dutch].

Recent Developments Overseas in the Welding Industry. E. H. Witt. (Australasian Engineer, 1948, Apr., pp. 56–59). Developments studied in travels in Great Britain and America include automatic welding, pipeline distribution of oxygen and acetylene for welding, flame-cutting, heavy cutting, flame-cropping of ingots, powder-flux-cutting, argon-arc and helium-arc welding, solid phase welding, flame-descaling, and the use of oxygen in steelmaking.—J. P. S.

New Welding Techniques. F. Charity. (Modern Machine Shops, 1948, vol. 20, May, pp. 146–148, 150, 152, 154: [Abstract] Metals Review, 1948, vol. 21, June, p. 26). The use of heliarc welding for stainless and carbon steel products is described.

Use of Jigs in Building Welded Railway Wagons. J. Růžek. (Svařování, 1948, vol. 3, Apr., pp. 33–38). [In Czech]. Full appreciation of the importance of using correctly designed jigs for building welded structures has resulted in a considerable increase in the rate of production of welded railway wagons in Czechoslovakia. The jigs used for production of closed cars are described; rotating jigs are used for welding the longitudinal beams and for setting up, tack-welding, and welding the sides, and a stationary jig for setting up and tacking the underframe which is welded in a welding jig. The jigs used for production of open steel wagons are also described, and pictures of the jigs are reproduced. The buffer parts are fitted into suitably designed jigs and welded with Kjellberg automatic machines, using heavily coated electrodes 450 mm long. The sections contract slightly, and it has been found that the individual section should be made 0·1% longer to compensate.—E. G.

Technology of Butt Welding of Steel Rings of Large Diameter and Cross Section. V. I. Korovkin. (Avtogennoe Delo, 1948, Jan., pp. 27–28). [In Russian].

The Sulphur Reaction and Hot Cracking during Automatic Welding of Low-Carbon Steel under Flux. K.V. Lynbavskii. (Avtogennoe Delo, 1948, Jan., pp. 22–26 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, June, p. 56). Results of investigations show that hot cracking depends not only upon sulphur concentration but also on the form in which it is present. MnS or a solid solution rich in MnS is said to be less harmful than iron sulphides.

Results of Conference on Automatic Welding under Flux. E. O. Patona. (Avtogennoe Delo, 1948, Jan., pp. 1–21). [In Russian].

Reconditioning of Used Rolling-Mill Rolls by Deposition of Metal Using Welding Techniques. Yu. A. Kalachev. (Avtogennoe Delo, 1948, Jan., pp. 29–30). [in Russian].

Deformation of Plates of Carbon and Alloy Steels during Automatic Welding under Flux. V. M. Rybakov. (Avtogennoe Delo, 1948, Feb., pp. 15–20). [In Russian].

Production of Cutting Tools by Welding-On of a Cutting Edge Using Special Electrodes. V. V. Danilevskii. (Avtogennoe Delo, 1948, Feb., pp. 26–27). [In Russian].

Control of the Tempering of Structural Steel during Welding. N. N. Rykalin and L. A. Frydlyand. (Avtogennoe Delo, 1948, Feb., pp. 3–11). [In Russian].

Local Elastic and Plastic Deformation during the Welding of Rods on to Sheets. N. N. Prokhorov, N. V. Shiganov, and A. V. Mordvinsteva. (Avtogennoe Delo, 1948, Feb., pp. 12–15 [in Russian] : [Abstract] Metals Review, 1948, vol. 21, June, p. 54). Results of investigations show that deformation often takes place in cooling, resulting in cracks. The rate and amount of this deformation increases with increased plate width. Cooling the zone adjacent to the weld with water is proposed.

Welding Stainless Steels. (Engineer and Foundryman, 1948, vol. 12, Jan., pp. 59, 61 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Mar., p. 23). A discussion is presented of the difficulties encountered in the welding of certain stainless steels. Mention is made of the most suitable flux and electrodes.

The Processing of Aluminium-Steel Bonded Assemblies. M. G. Whitfield and V. Sheshunoff. (Modern Metals, 1948, vol. 4, Apr., pp. 13–15). Aluminium may be bonded to ferrous metals by pre-plating the latter with tin, zinc, or aluminium, and then casting or brazing the aluminium on to the prepared surface. For maximum fatigue strength the bond should be of minimum thickness. Examples are given of articles fabricated in this way, and photomicrographs of aluminium bonded to steel and cast iron, are shown. M. A. V.

Bum Welds—and What Makes Them. F. S. Dever. (Welding Engineer, 1948, vol. 33, Feb., pp. 36–39, 43 : [Abstract] PERA Bulletin, 1948, vol. 1, May, p. 448). The defects encountered in arc welding, gas welding, spot welding, and special welding processes vary for many reasons and their correction involves different procedures. This article deals with the identification and prevention of the defects most likely to occur, and their classification by the Ryan Aeronautical Co., San Diego, particularly in relation to the fabrication of stainless steel. The need is clearly shown for familiarity with faults and their causes when parts are being designed.

Methods of Calculating the Costs of Arc Welding in the Smaller Industries. G. Hancke. (Dansk Teknisk Tidsskrift, 1948, vol. 72, Feb., pp. 27–28). [In Danish].

Brazing Cast Iron. Recent American Developments with Great Potentialities. S. D. Heron. (Automobile Engineer, 1948, vol. 38, Apr., pp. 149–151). The fabrication of grey iron castings of complex design, *e.g.*, cylinder blocks, can be simplified by welding, but the bond obtained in bronze welding is not sufficiently reliable. The Kolene Corporation have now developed a combined cleaning and surface-preparation process, in which the work is suspended in an open container of catalysed salts and an electric current passed, which enables the surface to accept silver brazing. The advantages accruing from the use of silver brazing in fabricating castings are discussed.—M. A. V.

How Brazing Methods Affect Design of Details. S. DeDomenico and A. Squire. (Products Engineering, 1948, vol. 19, Apr., pp. 86–91). This paper describes the common methods of brazing, *i.e.*, hand torch, automatic torch, direct resistance, carbon resistance, salt-bath, furnace, and induction. The most suitable methods for a variety of metals, *e.g.*, carbon and alloy steels, cast irons, copper and its alloys, etc., are given, together with suggestions for positioning and clamping assemblies before brazing.—J. P. S.

The Use of Oxygen in Industrial Applications. E. Lewis. (Engineer and Foundryman, 1948, vol. 12, Jan., pp. 45–47, 49 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Mar., p. 23). The following points are reviewed : Flame-cutting of stainless steels ; possibility of oxygen-cutting steel 50 cm thick under a pressure of 10 kg/sq.cm ; use of oxygen to eliminate surface defects and oxy-acetylene welding.

MACHINING AND MACHINABILITY

Modern Uses of Hard Metals. H. Burden. (Metallurgia, 1948, vol. 38, May, pp. 27–33). Some of the applications of "hard metals," in this case tungsten carbide plus titanium carbide, bonded with cobalt, in metal- and wood-working, and in wear-resisting inserts, are described.—J. P. S.

Air Contamination during Machining of Beryllium Stainless Steels. A. C. Titus. (Journal of Industrial Hygiene and Toxicology, 1948, vol. 30, No. 1, pp. 29–31 : Metallurgical Abstracts, 1948, vol. 15, June, p. 489). The author discusses the question of the toxicity of beryllium and describes experiments in which air concentrations of beryllium were measured during the cutting, turning, and grinding of a steel containing 0·7% beryllium. The concentration can be kept below 1 μg per day provided that a local exhaust hood is fitted to grinding machines.

New Developments in Tool Steels. G. A. Roberts. (Tool and Die Journal, 1948, vol. 13, No. 12, pp. 76–78, 80).

The Machining of Stainless Steels. W. H. Crisp and W. Burnam. (Aircraft Engineering, 1948, vol. 20, May, pp. 151–153). Techniques are recommended for machining (*a*) martensitic hardenable steels containing carbon 0·12–0·35%, chromium 12–14% ; (*b*) ferritic non-hardenable steels containing carbon 0·10% max, chromium 14–30%, and (*c*) austenitic work-hardening steels containing carbon 0·05–0·20%, chromium 17–20%, and nickel 7–10%.—M. A. V.

Some Fundamental Factors Involved in Intermittent Metal Cutting Processes, with Special Reference to Shaping. K. J. B. Wolfe. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 120–142). The fundamental difference between continuous and intermittent cutting processes, as represented by shaping, is mainly due to the repeated impacts on the tool in the latter process ; in addition the tool moves at a non-uniform velocity in intermittent cutting. A relationship was found between the maximum tool velocity, tool striking velocity, and tool life.—R. A. R.

CLEANING AND PICKLING

Degreasing and Cleaning. R. Springer. (Metalloberfläche, 1947, vol. 1, Aug., pp. 200–206). A classified review is presented of the literature and patents for the period 1935–43 relating to degreasing and cleaning.—R. A. R.

Survey of the Cleaning Methods Used for Iron and Steel Surfaces. R. Mansell. (American Paint Journal, 1947, vol. 31, Sept. 1, pp. 54, 56, 60 : [Abstract] Corrosion, 1948, vol. 4, June, p. 29). The use of solvent cleaners, steam cleaning, phosphoric acid cleaners, vapour degreasing, alkaline cleaners, and electrolytic cleaners is discussed.

The Protective Effect of Pickling Inhibitors and Its Evaluation. I. H. Fischer. (Archiv für Metallkunde, 1948, vol. 2, Jan., pp. 1–9). Results of laboratory tests of the effect of pickling inhibitors sometimes differ considerably from those obtained in full-scale operations. The reasons for this are explained. An increase in temperature usually increases the degree of inhibition although the absolute attack by the acid may be higher. A difference in the acid concentration may markedly alter the effect of an inhibitor. Acid attack increases during the second stage of the pickling process when the bath is saturated with Fe_2SO_4, and it seems that this activation cannot be prevented by inhibitors. In the presence of trivalent iron, which acts as a depolarizer, the rate of solution of iron increases very rapidly and inhibitors are almost ineffective.—R. A. R.

The "Jenolite" Process for Removing Rust and Protecting Surfaces. (Machinery Lloyd, 1948, No. 3A, Feb., pp. 61–62).

New Pickling Technique in the Enamel Industry. G. Morren. (Verre et Silicates Industriels, 1947, vol. 12, p. 127 : British Ceramic Abstracts, 1948, Mar.–Apr., pp. 135A–136A). The new method described is termed "gaseous pickling," and in it the iron oxide on the surface of the metal, instead of being dissolved off by acid, is reduced to the metallic state by gas consisting of 1–20% hydrogen and 99–80% nitrogen, obtained by cracking ammonia. One kg of ammonia gives 4·5 cu.m. of this gas, much of which, not being actually used in the reaction, may be passed through the reduction chamber more than once. The optimum reduction temperature is 900° C, preferably obtained by electric heating, owing to the need for close control of the atmosphere. Since the cycle lasts from 2 to 4 min only, the parts are taken through the chamber on a woven-wire conveyor. The cost of equipment is offset by the speed, thoroughness, cleanliness, and reduction of labour required.

Metal-Treatment Processes Prior to Painting. A. R. King. (Paint Manufacture, 1946, vol. 16, pp. 73–76, 113–117, 217–227, 283–287, 303 : British Abstracts, 1948, B.II, Mar., col. 117). The importance of adequate cleaning to remove surface grease and dirt, supplemented in some cases by mechanical abrasion, is emphasized for all metals. For light alloys, adhesion of paint films to the natural oxide layers is insufficient. It is, therefore, necessary to remove the oxide layers by

acid pickling or to increase its thickness, or partly to replace it by a chromate layer. Paint films adhere better to chromate films than to anodically oxidized films. Phosphatizing processes are not entirely satisfactory for light alloys. For ferrous metals, cleaning the surface and, in addition, removal of all corrosion products, are of vital importance, processes such as wire-brushing, acid pickling, and solvent and alkali treatment being used. H_3PO_4 not only removes rust, but also forms a phosphate layer. Modern phosphatizing processes are reviewed.

Finishing Galvanized Iron Surfaces. I. Richards. (Organic Finishing, 1948, vol. 9, Feb., pp. 33, 36–40).

World's Largest Salt Bath for Descaling Plate and Sheet. J. S. Morris. (Industrial Heating, 1948, vol. 15, Apr., pp. 569–578, 710, 720–722). An illustrated description is given of a very large descaling plant recently completed for the Lukens Steel Company, Coatesville, Pa. The sodium hydride tank is 40 ft long × 6 ft 4 in wide × 12 ft deep and it is heated by immersed electrodes supplied by eight 100-kW star-connected transformers for 440-V, 3-phase, 60-cycle current.—R. A. R.

Molten Salt Bath Descaling Provides Greater Metal Savings. (Steel, 1948, vol. 122, Mar. 29, p. 90). Brief particulars are given of the large descaling plant of the Lukens Steel Co. (*see* preceding abstract).—R. A. R.

Batch Electropolishing of Small Parts. R. Vicker. (Steel Processing, 1948, vol. 34, May, pp. 259–260). Jigs made by the American Rolling Mill Co. for the electrolytic polishing of small parts, such as screws, springs, and small stampings consist of a perforated copper sheet anode on which the work rests, with an expanded stainless steel sheet cathode fixed above, and insulated from it. The electrolytes used are sulphuric acid plus glycol, or phosphoric acid plus organic compounds. The tension applied is 10 V D.C.—J. P. S.

Fabricating and Finishing Stainless Steel. Part IV. A. P. Schulze. (Metal Finishing, 1948, vol. 46, May, pp. 64–68, 79). The principal advantages of the electropolishing process as applied to stainless steel are enumerated and operating details are given.—M. A. V.

Electro-Polishing as a Practical Method of Finishing. L. W. Owen. (Machinist, 1948, vol. 92, May 22, pp. 93–98; June 12, pp. 182–184). In this review of the electropolishing the author deals with the following aspects: General information, qualities of the metal surface, shape of articles to be treated, preparation of the surface, nature of the metal, application to specific metal, and properties of the polished surface.—R. A. R.

Electrolytic Polishing of Metals. Laboratory Applications. L. Tassara. (Ingegnere, 1946, vol. 20, Mar., pp. 185–197 [in Italian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 1/2, p. 134).

The Fume Problem. W. G. Imhoff. (Wire and Wire Products, 1948, vol. 23, Apr., pp. 312–315, 318, 340; May, pp. 399–405, 435–436). The harmful effects of fumes in metal-treating problems, and means of eliminating them are discussed. In the first part, steam vapours, and fumes from alkaline and acid cleaners, fluxes, driers, and galvanizing plants are dealt with; the second part gives details of methods and equipment for controlling fumes. A bibliography is appended. R. A. R.

PROTECTIVE COATINGS

Utilization of Spent Liquors in the Plating Shop. R. Erdmann. (Metalloberfläche, 1947, vol. 1, Aug., pp. 191–192). Owing to the shortage of chemicals in Germany it is important to make the fullest use of all available materials. Uses for spent liquors from the plating shop are suggested, *e.g.*, the recovery of copper sulphate for copperplating solution, and the use of other solutions as dyes or for etching.—R. A. R.

Construction of a Laboratory Electrolyser for the Determination of the Influence of Inter-Electrode Distance on the Deposition per Unit Current. I. E. Vilkomirskii, G. F. Valdman, and A. G. Novak. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 503–504). [In Russian]. Two arrangements of electrode pairs are described which, by ensuring that equal currents flow between each pair, enable the amounts of metal deposited by a given current with varying inter-electrode distance to be easily compared.—S. K.

Plating Speed, and Structure of Hard Chromium Deposits in Chromium Baths Abnormally High in Sulphuric Acid. R. Bilfinger. (Archiv für Metallkunde, 1948, vol. 2, Jan., pp. 27–30). A high rate of chromium plating can be obtained in chromium baths containing more than 1·2% of H_2SO_4 when the H_2SO_4 concentration, current density, and bath temperatures are all increasing. With increasing H_2SO_4 concentration and constant current density the rate of deposition decreases, but higher current densities may be used than in baths with lower H_2SO_4 concentration, the net effect being increased rates of deposition.—R. A. R.

Study of Thick Chromium Plating in Argentina. C. Roitman. (Revista de la Faculdad de Ciencas Químicas: Universidad Nacional de La Plata, 1945, vol. 20, pp. 41–51: Chemical Abstracts, 1948, vol. 42, May 20, col. 3270). Industrial applications of thick chromium plating are reviewed. Concentrations of 410 g/l of CrO_3 and 1% as much sulphate ion at 55–65° and 30–90 amp/sq.dm. were confirmed as good operating conditions.

A New Chromium-Diffusion Process. (Oil Engine and Gas Turbine, 1947, vol. 15, Dec., p. 265). Particulars are given of the results achieved by a "chromizing" process by which steels and cast iron can be impregnated with chromium to a controlled depth in the 0·0005–0·025-in range. Examples of its application for parts to resist corrosion, heat, and abrasion are given.—R. A. R.

Mechanism of Electrodeposition of Nickel. Part III—Influence of Selenium Dioxide Addition to the Structure and Internal Stresses of Nickel Deposits. G. S. Vozdvizhenskii. (Journal of Applied Chemistry, U.S.S.R., 1947, pp. 1171–1175 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, June, p. 26). It was found that SeO_2 additions to the electroplating bath, even in very small amounts, affect to a certain extent the structure and appearance of nickel deposits. It is believed that SeO_2 serves as a catalyst for saturation of the deposit with hydrogen.

Cathodic Crystallization of Nickel. S. Ya. Pasechnik and M. G. Popova. (Trudy Khar'kovskogo Khimiko-Tekhnologicheskogo Instituta im S.M. Kirova, 1945, vol. 5, pp. 104–112: Chemical Abstracts, 1948, vol. 42, May 20, col. 3270). Pitting in electrolytic nickel deposits is somewhat reduced but not entirely eliminated by addition of oxidants such as $NaNO_3$, $KCPO_3$, $KMnO_4$, MnO_2, or H_2O_2. The tendency to pitting is independent of the preliminary preparation of the basis metal and is the same on iron, copper, tin, lead, and nickel. Reversal of the current at regular intervals, *e.g.*, every 10 min for 10–20 sec at current density 10 amp/sq.dm., helps to prevent pitting. With soluble anodes (in the presence of chlorides in the electrolyte) pitting is considerably heavier than with passive anodes; the effect is attributed to the small amount of highly oxidized anode sludge formed on insoluble or only partly soluble anodes. This explanation is confirmed by the observation that enclosing the anodes in cloth bags, thus preventing transfer of that sludge to the cathode, resulted in pitted deposits. With the bags eliminated, pit-free deposits were produced in the same electrolyte ($NiSO_4$ $7H_2O$ 350 g/l; H_2SO_4 10 g/l, temp 80°, cathodic current density 10 amp/sq.dm., anodic current density 5 amp/sq.dm.). Filtration or sedimentation of the electrolyte also resulted in pitting. Only the sludge formed on a passive anode is effective in preventing pitting; the sludge loses its efficacy on standing owing to the decomposition of the unstable higher oxides. In the presence of chloride, very high anodic current density is necessary to ensure sufficient passivity of the nickel anodes, with 0·3 g/l NaCl, over 20 amp/sq.dm. That the suppression of the pitting is not due to anodic oxygen was demonstrated with platinum anodes, which proved ineffective. On the other hand, pitting disappeared with lead anodes; this is taken as proof of the determining role of Ni^{+3} and Ni^{+4} ions, which can be formed on lead anodes but not on platinum. With nickel anodes, pitting can be prevented if the electrolyte is kept free from chloride (not over 0·1 g NaCl/l), and the anodic current efficiency below 95%. The anode should appear coated with a golden-brown film of higher nickel oxides. As there is no sludge of the kind formed with highly soluble anodes, no diaphragms are necessary.

Thick Electrolytic Nickelplating. S. Ya. Pasechnik and M. G. Popova. (Trudy Khar'kovskogo Khimiko-Tekhnologicheskogo Instituta im S.M. Kirova 1945, vol. 5, pp. 113–124: Chemical Abstracts, 1948, vol. 42, May 20, col. 3269). Adhesion of nickel-plate to iron is improved decidedly by heating the plated sample to 500–900°, owing to mutual diffusion and alloying. The nickel deposits were produced on sheet iron

0·3–5 mm thick, in $NiSO_4$ $7H_2O$ 350 g/l, NaCl 1 g/l; Na_2SO_4 10 H_2O 180 g/l; acidity corresponding to 10–15 ml 0·1 *N* NaOH per 10 ml, temperature 70–80°, c.d. 10–15 amp/sq.dm. (1) With an intermediate 0·002–0·003 mm copper layer, adhesion of nickel 0·02–0·03 mm remained poor (in bending tests) after 1 hr heating in hydrogen at up to 700° but was sharply improved at 800°. At the same time the copper layer was no longer visible on micrographs; a granular layer of the ternary alloy appeared in its place. The raising of the temperature to 850–900° had no further effect. Thicker copper layers require longer heating. (2) Without an intermediate copper layer, nickel deposits as thin as 0·02 mm proved poorly adherent on bending; micrographs showed a gap between the iron and nickel. Satisfactory adhesion of deposits up to 0·2 mm thick was attained after 5 min heating at 900°. The thickness of the alloy layer formed at 900°, 0·05 mm, could be measured directly after 10 hr treatment; hence, the thickness of that layer after 5 min could be calculated to be 0·004 mm; [? 0·0004 mm]; this is sufficient to ensure perfect adhesion. No alloying takes place below 500°, even on prolonged heating; at 500° no less than 2–3 hr are necessary, at 700–800° 1 hr is enough. Whilst heating at up to 800° embrittles the nickel, the deposit is perfectly ductile after heating at 900°. (3) The treatment does not necessarily require a hydrogen atmosphere and can be carried out in air. The thin oxide film formed at 700° can be removed with emery paper; at 900°, the oxide film is hard and resists abrasion. Slow heating up from room temperature to 300° (10–20 min) is essential for gradual outgassing. The article should then be transferred quickly to a furnace kept at 900°, to avoid too long exposure to 500–600° where the nickel is embrittled; cooling down from 900° should be fast. (4) In boiling NaOH, 80 g/l, nickel and the heat-treated nickel-plated iron lost 5 g/sq.m. in 250 hr as against 341 g for iron. Before the loss of weight, the nickel (but not the iron) shows a passing slight gain of weight. In boiling NaOH saturated with NaCl, in boiling $KClO_3$ (1200 g/l) with 450 g/l $CaCl_2$, and in ammoniacal Na_2CO_3 at 60–70°, the treated nickel-plates behaved exactly like pure nickel.

Corronizing Process. (Wire and Wire Products, 1948, vol. 23, Apr., pp. 311, 343–345). The nickel–tin and nickel–zinc corronizing processes are described. Nickel is first deposited on the steel to be protected, and zinc or tin over the nickel, the material being finally heated to obtain diffusion. The protective effect depends on the fact that a series of alloy layers of progressively changing composition is formed, each layer being sacrificial to the one below it. The properties of corronized coatings are described.—M. A. V.

Electricity in the Production of Tinplate. G. Genin. (Electricité, 1947, vol. 31, Nov., pp. 203–207).

Protecting Metal Surfaces by Tin Diffusion. (Metalloberfläche, 1947, vol. 1, Aug., pp. 185–187). A brief description is given of a process of coating brass and steel with tin by dipping the part in a stannous chloride bath for 15 to 60 sec in the case of steel, and about 15 min for brass. The tin layer is about 0·004 mm deep, but as the reaction is of the base-exchange type the actual increase in dimensions is only about 0·0015 mm.—R. A. R.

The Electrolytic Tinning of Iron and Steel Parts. A. Kufferath. (Metalloberfläche, 1947, vol. 1, Sept., pp. 221–223). The advantages of electrolytic tinning are pointed out and the literature on the process, with recommended bath compositions, is reviewed.—R. A. R.

Ridge Formation on Tinplate. A. Hamelain. (Sheet Metal Industries, 1948, vol. 25, June, pp. 1125–1126, 1140). Theories for the formation of ridges on tinplate are critically examined. Experiments indicate that tin ridges could be suppressed by ensuring that the tin coating solidifies, either under a continuous film of oil, or before leaving the oil bath. This method would result in a large consumption of oil. Another method has been successfully used on a small scale. This was to increase the height of the oil level above the top pair of grease-pot rollers and to provide a system of cooling the oil at each side of the pass line of the sheet so that it would entrain a thin continuous film of oil.—R. A. R.

The Testing of Tinplate. I.—Visual Examination and Mechanical Tests. II.—Chemical Tests. T. Fielding. (Tin Printer, 1947, vol. 23, No. 274, pp. 5–7; No. 275, pp. 8–9).

Recent Investigations into the Hot-Dip Tinning of Steel Spoons and Forks. W. E. Hoare and K. W. Caulfield. (Sheet Metal Industries, 1948, vol. 25, May, pp. 925–930, 932). *See* Journ. I. and S.I., 1948, vol. 159, June, p. 225.

POWDER METALLURGY

Powder Metallurgy—Notes on Steel and Alloy Steels. H. W. Greenwood. (Iron and Steel, 1948, vol. 21, May, pp. 183–184). The author describes a number of methods for preparing steels by sintering soft iron powders with white cast iron and/or graphite. He stresses the importance of maintaining reducing atmospheres and avoiding the presence of water vapour and suggests that the use of hydrides of such metals as tantalum, titanium, and zirconium provides a convenient method of preparing steels containing these elements by powder metallurgy.—J. P. S.

High Temperature Materials by Powder Metallurgy. C. G. Goetzel. (Iron Age, 1948, vol. 161, Apr. 29, pp. 78–81). The author suggests that few alloys produced by conventional means will prove serviceable at the higher temperatures now in sight in gas turbines and similar applications. Powder-metallurgy techniques, however, particularly that of "infiltration," will render possible the manufacture of alloys of metals difficult to fuse, such as tantalum and molybdenum, and may lead to the development of combinations of metals and ceramics.—J. P. S.

The Production and Properties of Sintered Carbides. B. Zacharzewski. (Hutnik, 1947, vol. 14, June, pp. 292–301). [In Polish]. The preparation and properties, including hardness, density, thermal conductivity, and electrical resistance of a number of sintered carbides are discussed. The materials include tungsten carbide with various amounts of cobalt, and mixed tungsten and titanium carbides.

Friction in Powder Metallurgy. H. W. Greenwood. (Metallurgia, 1948, vol. 37, Apr., pp. 283–284). The effect of friction, both between the particles themselves and also between the particles and the die walls, in the pressing of powder-metallurgy compacts, and the factors influencing it, are described. A. E. C.

The Hardening of Iron–Zinc and Cobalt–Zinc Alloys. J. Schramm and A. Mohrnheim. (Zeitschrift für Metallkunde, 1948, vol. 39, Mar., pp. 71–78). Specimens of iron–zinc alloys (Zn 6–37%) and iron–cobalt alloys (Co 20–53%) were produced by powder metallurgy and their density, magnetic and mechanical hardening properties, and corrosion resistance were investigated. Precipitation hardening was heterogeneous and on a microscopic scale. This was established by examination under the microscope and confirmed by X-ray and magnetic investigations. The dissociation of the supersaturated solution causes an increase in hardness. The iron–zinc alloys did not corrode in the atmosphere but were less resistant to aqueous solutions.—R. A. R.

Present Position of the Powder Metallurgy of Iron. H. Timmerbeil and O. H. Hummel. (Archiv für Metallkunde, 1948, vol. 2, Jan., pp. 30–35). This review covers all stages of the powder-metallurgy process for iron, including the properties and applications of the products.—R. A. R.

PROPERTIES AND TESTS

Questionnaire on the Evaluation of Materials on the Results of Mechanical Tests. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 446–473). [In Russian]. The replies of eight Russian authors are given to a questionnaire, submitted by the editors of "Zavodskaya Laboratoriya," in which information was solicited on the following problems of the evaluation of materials on the results of mechanical tests: (1) The division of mechanical properties into primary and secondary categories and the inclusion of plasticity in the latter; (2) the connection between the structure of an alloy and its mechanical properties; (3) the significance of yield point, yield strength, and breaking-load data for the estimation of structural behaviour; (4) the characteristics to be used for estimating the plasticity of structural materials and the effects of this property on normal structural behaviour; (5) the occasional failure of tests to indicate brittleness in use; (6) the anomaly of satisfactory service given by materials of low resilience in exacting circumstances, for example, cast-iron crankshafts; (7) the type of specimen to be used for fatigue tests and the possibility of estimating the order of magnitude of the fatigue limit of smooth specimens from the

static properties of the material; (8) the extent to which tests of creep and slow fracture give a true evaluation of the behaviour of a material at high temperatures, or when temperature varies widely and rapidly, and the need for additional tests when this latter condition is envisaged; (9) the type of laboratory test most suitable for the evaluation of workability, and the possibility of using mechanical characteristics or microstructure for this purpose; (10) the property the variation of which gives the best indication of the deviation of a material from a standard; (11) the relative sensitivity of breaking tests and of tests carried out in the range of plasticity; and (12) the application of statistical methods for the evaluation of homogeneity and conformity with standards for raw materials.—S. K.

Plotting a Smooth Curve through Scattered Points. Z. Wusatowski. (Hutnik, 1947, vol. 14, June, pp. 287–292). [In Polish]. By mathematical analysis, the author indicates how linear, logarithmic, and other equations may be derived for the development of smooth curves in a field of scattered values.—W. J. W.

Electronic Measurement. D. M. Swatton. (Mass Production, 1948, vol. 24, p. 52: British Ceramic Abstracts, 1948, Mar.–Apr., p. 141A). To illustrate a few of the ways in which electronic techniques are used in industry, a description is given of two types of electronic micrometer, and of a photo-electric pyrometer for temperature measurements above 750° C.

An Experimental Study of the Influence of Various Factors on the Mode of Fracture of Metals. P. G. Jones and W. J. Worley. (American Society for Testing Materials, 1948, Preprint No. 17). This paper presents experimental results on the influence of combinations of the factors rate of strain, stress concentration, and state of stress on the mode of fracture of a 0·13% carbon semi-killed steel, a 0·17% carbon rimmed steel, a 0·97% carbon steel, and an aluminium alloy. The rate of strain was varied by making static and impact tests in tension and torsion, and tests were made at temperatures down to − 310° F. Certain combinations of external conditions may cause brittle behaviour of a metal which normally exhibits great ductility, *e.g.*, a low-carbon steel exhibited a fracture of almost a brittle type when subjected to a high rate of strain at a low temperature.—R. A. R.

A Universal Testing Machine for Static Tests. R. Nilson. (Teknisk Tidsskrift, 1948, vol. 78, May 22, pp. 346–347). [In Swedish]. A description is given of a universal testing machine with which tensile, compressive, and torsional tests can be made. It was developed by M. Prot, Paris.—R. A. R.

Quantitative Methods of Studying Aeolotropy in Steel Sheet and Strip. N. F. Astbury and A. E. De Barr. (Sheet Metal Industries, 1948, vol. 25, May, pp. 911–916, 921). It is shown how aeolotropy, or anisotropy, in steel sheets and strips can be studied by information derived from the measurements of Young's modulus, and how in certain cases estimates can be made of the actual degree of crystal orientation present. R. A. R.

Photoelastic Investigation of Stress-Relieving Fillet Curves. E. Chapman. (Product Engineering, 1948, vol. 19, May, pp. 138–141). A description is given of a photoelastic polariscope the components of which are mounted on two 1-in. ground steel bars to ensure accurate alignment. The apparatus is 22 in wide and 6 ft long with all controls centralized at the viewing screen, including control of the load on the specimen. The preparation of the plastic model is described in detail. An example is given of the application of the apparatus to determine the optimum design of elliptical fillet at the root of splines in a compressor wheel running at high speed.—R. A. R.

The Brittle Lacquer Method of Determining Stresses. (Metallurgia, 1948, vol. 37, Apr., pp. 290–292). The lacquer method of assessing the location and magnitude of strains and the corresponding stresses is described. The compositions and properties of some lacquers are discussed. An electrometric method of determining the continuity of the coating is explained. Examples of the test are given. The information is taken from Chapter IV of "Stress Determination in Machine Parts by Means of Tensometers and Lacquers," by N. R. Goncharov (Leningrad–Moscow, 1946).—A. E. C.

The Optical System in Photoelastic Observations. H. T. Jessop. (Journal of Scientific Instruments, 1948, vol. 25, Apr., pp. 124–126). It is shown that if a projected fringe pattern is accurately to represent stress distribution in a parallel plate model, a large source of light must be used, in conjunction with a diaphragm in the projecting lens; also, a collimating lens is necessary, the diaphragm being placed at its principal focus.—M. A. V.

The Notch Effect on the Cold Brittleness of Steel. E. M. Shevandin. (Journal of Technical Physics (U.S.S.R.), 1947, vol. 17, Oct., p. 119 [in Russian]: [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, June, p. 256). The present paper deals with experiments undertaken to investigate the effect of notch shape on the critical temperature of brittleness of mild steel. The specimens used were of soft mild steel containing 0·2% of carbon, some of them plain and some with notches of various sizes.

The experimental data obtained are used by the author for the construction of a three-dimensional diagram showing the cold brittleness of steel in relation to the speed of deformation, temperature, and coefficient of notch shape. The use of this diagram is suggested in calculations dealing with the cold brittleness of mild steel.

Cold Brittleness of Welded Structures at Low Temperatures. A. S. Ogievetskii. (Avtogennoe Delo, 1947, Dec., pp. 18–19. [In Russian].

On the Mechanism of Cold Brittleness in Metals. T. Sutoki. (Tohoku Imperial University, Nov., 1944: Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1948, vol. 5, Feb. 25, pp. 65–75). The author describes tension and impact tests on Flodin iron, steels containing 0·3–0·7% carbon, zinc, and aluminium, from the boiling point of nitrogen up to 200° C. For the impact tests six types of test-piece were used, five bearing variously shaped notches, and the sixth being unnotched but thinner. The minimum thickness was in all cases the same. Results showed that the speed of deformation of the test-piece increased as the angle of the notch decreased; moreover, as the speed of deformation decreased the transition temperature fell and brittleness increased.—J. C. R.

Plasticity and Brittleness. S. I. Gubkin. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 474–486). [In Russian]. Various terms used in the discussion of plasticity and brittleness are defined and the relationships between the factors governing these properties are illustrated schematically and mathematically. Twenty-three possible types of mechanical deformation are listed, together with the stress conditions giving rise to each, and the diagramatic representation of deformation properties is discussed. The mechanical properties of a number of alloys are considered, and a description is given of a pendulum impact machine for testing at high temperatures. In conclusion, some general questions referring to the testing of materials are dealt with.—S. K.

Brittle Fractures in Mild-Steel Plates.—Brittle Failure of American Ship Plates. W. Barr. (Engineering, 1948, vol. 165, Feb. 27, pp. 208–210; Mar. 5, pp. 222–223). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 300.

Brittle Fracture in Mild Steel Plates. C. F. Tipper. (Engineering, 1948, vol. 165, June 11, pp. 568–571; June 18, pp. 592–595; June 25, pp. 605–607). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 300.

Steel Weldability and Its Testing. A. Benes. (Svařování, 1948, vol. 4, May, pp. 49–55). [In Czech]. After discussing generalities on weldability, notch-toughness tests carried out on samples cut from and near welds are mentioned, and it is stated that such tests are useful only for testing steels which are subject to ageing. The Jominy test is described in detail; this test method has proved satisfactory, particularly in the case of automatic welding.—E. G.

Applicability of Automatic Structural Welding of Low-Carbon Steels at Low Temperatures. B. I. Medovar and A. E. Asnis. (Avtogennoe Delo, 1947, Dec., pp. 15–17 [in Russian]: [Abstract] Metals Review, 1948, vol. 21, May, p. 48). Testing of a specimen welded under normal conditions and one welded at −20° C showed 15% to 20% lower impact strength of the latter. However, cold brittleness was not increased.

Experimental Method of Stress Analysis. J. H. Lamble. (Engineering, 1948, vol. 165, May 7, p. 436). Examples are given of the use of brittle lacquers for studying stress distribution in flat plates subjected to hydrostatic loading.—M. A. V.

The Analysis of Strain and Its Graphical Representation. A. H. Willis. (Engineering, 1948, vol. 165, May 14, pp. 457–460). The analysis of strain and its representation are explained mathematically in a manner designed to serve as

an introduction to the subject for engineers intending to adopt strain-gauge equipment in research and development work.—R. A. R.

Internal Stresses in Metals. W. A. Wood and N. Dewsnap. (Nature, 1948, vol. 161, May 1, pp. 682–683). X-ray diffraction studies by Wood and his co-workers led to the result that internal stresses in a number of metals were not irregular but were related in magnitude and direction to the previously applied stress and were therefore not of the intergranular type envisaged by E. Heyn. G. B. Greenough has suggested Wood's results still might be explained by the intergranular stresses postulated by Heyn since, in a given specimen, the X-rays measure the stresses in grains of the same crystallographic orientation only. Reasons for rejecting this theory are now given, the authors finding that two types of internal stress may arise during plastic deformation, namely, (1) irregular stresses perhaps explicable by the Heyn hypothesis of anisotropy, and (2) the regular type of internal stress which must be associated in a fundamental manner with the response of the metal lattice to external stress.—R. A. R.

Internal Stresses in Metals. G. B. Greenough. (Nature, 1948, vol. 161, May 1, p. 683). The author comments on the conclusion of Wood and Dewsnap that two types of internal stress may arise during plastic deformation (*see* preceding abstract) and advances additional reasons why his hypothesis of Heyn stresses provides an adequate explanation of the observation of residual lattice strains, and why it does not appear to be necessary to postulate any further type of internal stress.—R. A. R.

Influence of Small Elastic Stresses on the Initial Transformation Susceptibility of Ferromagnetic Substances. S. V. Vonsovskii. (Journal of Experimental and Theoretical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1094–1105 [in Russian] : [Abstract]. Metals Review, 1948, vol. 21, June, p. 10). Dependence of initial transformation susceptibility on low external stresses was established. It is shown that it depends primarily on the magnetic structure of the test specimen and has maxima and minima whose locations are defined by the " toughness " of the specimen. There are ten references.

Laws of Deformation of Solid and Liquid Bodies. G. Gurevich. (Journal of Technical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1490–1502 [in Russian] : [Abstract] Metals Review, 1948, vol. 21, June, p. 10). It is shown that Maxwell's well-known equation of relaxation, when exponential dependence of the time of relaxation on stress is assumed, may be used as a first approximation to express the process of deformation of amorphous and crystalline bodies. There are fifteen references.

The Acoustic Strain Gauge. (Muirhead Technique, 1948, vol. 2, Jan., pp. 5–7 : [Abstract] Bulletin and Foundry Abstracts of the British Cast Iron Research Association, 1948, vol. 9, May, p. 174). A description is given of the acoustic strain gauge, or, as it is sometimes called, the vibrating wire gauge, the principle of which is that the change in frequency of the vibration of a stretched steel wire, clamped to the structure under test, gives a direct measure of the change in strain occurring in the structure. The stretched wire of the test gauge is plucked electromagnetically and the note emitted is matched against the frequency of the note emitted by a second steel wire, the tension of which can be varied by a calibrated control. Among the applications mentioned it is stated that the method has been successfully employed to measure the strains induced in the cast-iron girders of a railway bridge by the crossing of an express train at a speed of 60 m.p.h.

Simplified Dynamic Strain Equipment. W. J. Worley. (Instruments, 1948, vol. 21, Apr., pp. 330–332).

Photo-Elasticity. J. Ward. (Institute of Marine Engineers : Automobile Engineer, 1948, vol. 38, May, pp. 193–196 ; June, pp. 223–227). A comprehensive account of recent advances in photo-elastic testing technique is given under the following headings : (1) Construction of polariscopes ; (2) principal stresses and principal plane of stress ; (3) circularly polarized light ; (4) materials for moulds ; (5) separation of principal stresses ; (6) stress in a material being turned ; (7) contact stresses in rollers and discs ; (8) forced fits ; (9) three-dimensional photo-elasticity ; (10) scattered light method and (11) design of apparatus.—R. A. R.

Measurement of the Elastic-Viscous Properties of Dispersed Systems by the Method of the Tangential Displacement of a Plate. S. Ya. Veiler. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 432–434). [In Russian]. The technique developed by P. A. Rebinder and his school for the study of the elastic-viscous properties of disperse systems is described and some examples of its applications are given.—S. K.

Surface Stresses in Polished Steel Shafts. H. Kohsok. (Publications de l'Institut de la Recherche Scientifique, 1947, No. 2, Oct., pp. 42–48 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 3/4, p. 588).

Effect of Fatigue on Tension-Impact Resistance. W. H. Hoppman, jun. (American Society for Testing Materials, 1948, Preprint, No. 29). The possibility of using high-velocity tension-impact tests to determine the loss of impact resistance caused by fatigue on metals is examined. Specimens cut from a low-carbon steel plate in a known state of fatigue were subjected to tension-impact tests at velocities up to 120 ft/sec. At the higher testing velocities the energy absorbed and the elongation were about 30% less in the fatigued specimens than in the as-received state. Tension-impact tests may have considerable value in studying fatigue damage to structures in service.—R. A. R.

Some Characteristics of Residual Stress Fields during Dynamic Stressing above the Endurance Limit. J. B. Duke. (American Society for Testing Materials, 1948, Preprint No. 30). Specimens of a 0·20% carbon steel and a chromium–nickel–molybdenum steel were subjected to bending fatigue and then inserted in the high-frequency coil of a DuMont Cyclograph so that the eddy-current losses and hysteresis could be measured in relation to the fatigue damage. The testing technique is comparatively simple and enables data for predicting fatigue failure to be obtained regardless of the heat-treatment or composition of the steel.—R. A. R.

Shot Peening Castings. C. R. Austin. (Steel, 1948, vol. 122, Apr., 5, pp. 79–84). The effect of peening is to set up compressive stresses in the surface layers of the metal enabling it to withstand higher tensile stresses ; though insufficient data for GA Meehanite have been accumulated, the author believes that peening will improve the fatigue properties of this alloy.—J. P. S.

Hardenability. F. P. Peters. (Scientific American, 1947, vol. 176, May, pp. 210–213 : [Abstract] Centre de Documentation Sidérurgique, 1948, vol. 5, Feb., p. 42). A general review is presented of the hardening of steels, the properties of hardened steels, and the importance of the Jominy test.

The Hardness of Steel. L. F. Keeley. (Machinery Lloyd, 1948, vol. 20, Mar. 13, pp. 68–70 : [Abstract] PERA Bulletin, 1948, vol. 1, June, pp. 486–487). The author commences by discussing the property of hardness, giving Mohr's hardness scale. The respective principles, advantages, and applications of the Brinell, Vickers Pyramid, and Rockwell hardness tests are described. Shore scleroscope and Herbert pendulum hardness tests, depth-hardening properties of steels and the Jominy " end-quench " tests for assessing them, significance of grain-size and its evaluation by the McQuaid-Ehn test, influence of metal section on depth hardening, application of alloys for increasing hardening capacity of steels, and the use of various quenching media are discussed.

The Evaluation of Steels by Chemical Analysis and by the Jominy Test. J. M. Vielle. (Métallurgie, 1948, vol. 80, May, pp. 25, 27, 29–31). An account is presented of the work of various investigators on the influence of composition on the elastic properties and hardenability of steels. Attempts to relate Jominy hardness test results to composition have not proved satisfactory. Other work on the relationship between Jominy test results and the curves indicating transverse hardness of hardened bars is reviewed.

Contribution to the Study of the Problem of Hardness. P. Dubois and A. Dumez. (Mémoires de la Société des Ingénieurs Civils de France, 1947, vol. 100, May–June, pp. 343–371). Part I contains a review of static and dynamic methods of hardness testing. Part II deals with the following factors : Conditions of penetration and recording of the load/depth-of-impression curve ; rôle of the nature and shape of the indenter ; relative influence of the following phenomena : Elasticity, plasticity, friction of indenter on the material under test ; and comparison of results with those obtained from tensile, compression, and impact tests.—J. C. R.

Inter-Relation of Hardenability and Isothermal Transformation Data. W. I. Pumphrey and F. W. Jones. (Journal

of The Iron and Steel Institute, 1948, vol. 159, June, pp. 137–144).

Microhardness Measurement. E. B. Bergsman. (Industritidningen Norden, 1948, Feb. 11, pp. 29–33 : [Abstract] Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 6). A microhardness measuring instrument and its operation are described. Possible practical applications of the method are considered.

A Simple Laboratory Test to Determine Data Necessary for the Production Heat-Treatment Process. J. Mowat and J. Sloan. (West of Scotland Iron and Steel Institute, Apr., 1948, Preprint). A laboratory test which has proved helpful in the development and heat-treatment of alloy steels for forgings and armour plate is described. This "Refining Bar Test" consists of subjecting two standard bars, in different heat-treated conditions, to a heat gradient in a specially designed furnace. The test results are given in the form of graphs indicating the relation between Brinell hardness and the temperature (*a*) from which the steel has been quenched subsequent to annealing, and (*b*) at which the steel has been tempered after hardening ; in addition, it is possible to relate the Izod impact value to the treatment temperature and to study the nature of the fracture.—R. A. R.

Temper Brittleness. F. Pobořil and V. Koželev. (Iron and Steel, 1948, vol. 21, June, pp. 289–294 ; July, pp. 319–322). This is an English translation of a paper which appeared in *Hutnické Listy*, 1946, vol. 1, No. 5, pp. 97–101 ; No. 6, pp. 130–133 ; No. 7, pp. 155–158. The authors distinguish between "permanent" and "temporary" temper brittleness ; a steel has permanent temper brittleness when the brittleness is not removed by changes in the rate of cooling after tempering. The results of impact tests at + 20° C and −78° C on low-alloy steels tempered at various temperatures and of explosive tests on a heat-treated chromium–nickel–vanadium steel are presented and discussed. In the latter tests charges up to 5·25 g of explosive were electrically fired in small piston-like specimens and the type of deformation or fracture designated by a number. It was found that the impact resistance in both ordinary and explosion tests of steels prone to permanent temper brittleness, and of equal tensile strength, increases with rising tempering temperature ; there was also a linear relation between the resistance to explosion and the impact resistance at −78° C.—R. A. R.

Friction of Solid Films on Steel at High Sliding Velocities. R. L. Johnson, D. Godfrey, and E. E. Bisson. (National Advisory Committee for Aeronautics, 1948, Technical Note No. 1578 : [Abstract] Metals Review, 1948, vol. 21, June, p. 10). Results of kinetic friction experiments on steel specimens with thin inorganic solid films over a range of velocities between 50 and 8000 ft/min and loads from 169 to 1543 g are given. MoS_2 is very effective in reducing friction, and is very tenacious and chemically and thermally stable. Fe_3O_4 was beneficial on run surfaces whereas α-Fe_2O_3 was not. With films of the type formed by extreme-pressure-lubricant additives, $FeCl_2$ was more effective in reducing friction than FeS. There are nineteen references.

An Indentation Method for Measuring Wear. (Machine and Tool Blue Book, 1948, vol. 44, May, pp. 141–144, 148, 150, 152 : [Abstract] Metals Review, 1948, vol. 21, June, p. 32). The use of the McKee wear gauge, developed at the Bureau of Standards, is described. As little as 0·000001 in is measured under favourable conditions.

Friction and Wear of Metals in the Presence of Liquid Gases. P. T. Riumin and Yu. N. Riabinin. (Kislorod, 1946, No. 4, pp. 35–41 [in Russian] : [Abstract] Engineers' Digest, New York, 1948, vol. 5, May–June, p. 186).

The Influence of Manufacturing Factors on the Magnetic Properties of Transformer Sheets. G. Delbart, R. Potaszkin, and M. Sage. (Société Française de Métallurgie : Revue de Métallurgie, 1947, vol. 44, July–Aug., pp. 193–209 : Sheet Metal Industries, 1948, vol. 25, Mar., pp. 503–507, 508 ; May, pp. 905–910 ; June, pp. 1127–1134, 1142). Theoretical considerations relating to the magnetic properties of transformer steel sheets are outlined, and a report of the authors' investigations on the influence of manufacturing processes, particularly the rolling and annealing conditions on these properties, is presented. In general, ingots rolled to sheets without an intermediate reheating have lower core loss than those rolled in two heats, and the losses are lower the higher the temperature at the end of rolling. Sheets of the same carbon content have different magnetic properties. Decarburization is slight during the rolling of sheet bars and in the first stages of final rolling, but is much more pronounced in the last stage.—R. A. R.

Tensometric Method for the Determination of Coercive Force. B. D. Lapkin. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 505–506). [In Russian]. A method of measuring coercive force with the help of an instrument for measuring the deformation of a loaded mechanism is described, and an example is given to show the applicability of the method to the magnetic testing of steels.—S. K.

New Materials for (Magnetic) Techniques with Weak Currents. R. Goldschmidt. (Helvetica Physica Acta, 1947, vol. 20, pp. 458–459 : Chemical Abstracts, 1948, vol. 42, June 20, col. 4109). Properties of the following magnetic materials are discussed briefly : Alnico, Hypersil, Ferroxcube, Supermalloy, and Superisoperm.

Modern Permanent Magnet Materials. J. H. Jupe. (Electrical Manufacturer, 1948, vol. 4, Mar., pp. 81–83 : [Abstract] PERA Bulletin, 1948, vol. 1, June, pp. 482–483). The precautions to be observed when designing magnets from Alnico alloys are discussed and limiting sizes, proportions, and tolerances are given for sand-cast, precision-cast, and sintered magnets. Factors affecting the manufacturing method to be adopted are outlined and the properties of the available grades of Alnico are compared. A data-sheet giving the electrical characteristics and physical properties of cast and sintered Alnico is also included.

Permanent Magnet Alloys. E. M. Underhill. (Electronics, 1948, vol. 21, No. 1, pp. 52–53 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3301). Magnetic, physical, and mechanical characteristics of forty-two permanent-magnet materials are described. The maximum energy product of the more recent Alnico alloys is about fifteen times that of the old 5% tungsten steels. "Alnico V" contains Al 8%, Ni 14%, Co 24%, Cu 3%, balance Fe.

Magneto-Spin Resonance in Ferromagnetic Materials Induced by Waves in the Centimeter Range. E. K. Zavioskii. (Journal of Experimental and Theoretical Physics U.S.S.R., 1947, vol. 17, Oct., pp. 883–888 [in Russian] : [Abstract] Metals Review, 1948, vol. 21, May, p. 8). Phenomenon was investigated in a series of ferromagnetic alloys such as electrolytic nickel, transformer iron, and alloys of the "Mishima" type (composition not given).

Influence of the Arrangement of Magnetic Moments on the Magnetic Properties of Polycrystalline Ferromagnetic Materials. M. V. Dekhtyar and G. M. Raiskaya. (Journal of Experimental and Theoretical Physics, U.S.S.R., 1947, vol. 17, Oct., pp. 911–914). [In Russian].

Non-Destructive Testing of Drill-Pipe. R. C. McMaster and H. M. Banta. (Petroleum Engineer, 1947, vol. 19, Nov., p. 64 : [Abstract] Journal of the Institute of Petroleum, 1948, vol. 34, May, p. 125A). Non-destructive methods of inspecting and testing drill-pipe are required for two purposes : (1) To prevent faulty pipes from being dispatched from the mills for drilling-rig service as this would cause early failures in the field ; and (2) to detect the effects of corrosion and fatigue in drill-pipe in use in the field and thus prevent "twist-offs" due to these causes. The nature of drill-pipe failures and their relation to drill-pipe defects are discussed ; the causes and effects of various mill defects, such as laps, seams, plug cuts, etc., are studied and compared with field defects resulting from corrosion and fatigue. Present mill- and field-inspection methods are outlined and several possible methods for mill- and field-testing are described. These include : (1) Magnetic particle ("Magnaflux") inspection ; (2) sensitive-surface magnetic field measurement ; (3) gamma-ray or X-ray inspection methods which respond to local stress concentrations ; (4) electric-current-conduction tests ; (5) eddy-current-induction tests ; (6) supersonic reflection and transmission methods ; (7) air, liquid, and vacuum leak tests ; (8) electromechanical caliper methods ; and (9) cyclograph testing. Procedures are suggested for improving both mill- and field-inspection of drill-pipe by the experienced use of one or more of these testing methods.

On the Physical Principles of Ultra-Sonic Waves and Their Use for Testing Materials. R. V. Baud. (Schweizerische Bauzeitung, 1948, vol. 66, Apr. 3, p. 185 ; Apr. 17, p. 215 : [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, May, p. 216). The author explains the properties of waves in general, with particular reference to their propagation through media of technical importance

such as air, oil, and steel, and to supersonic waves. He then describes some supersonic transmitters and receivers and their applications to the testing of metallic components for cracks and fissures. He concludes with remarks on instrument characteristics and design. Diagrams are given explaining principles of both permeability and echo-sounding methods. There is a number of references.

New Method for Measuring the Viscosity of Metals. C. Sălceanu. (Comptes Rendus, 1948, vol. 226, No. 22, May 31, pp. 1798–1800). A torsional oscillation method of measuring the viscosity of wire specimens is described. A horizontal thin rod of wood, 52 cm. long, carrying weights of 10 g each at each end, is attached at its mid-point to the middle of the vertical wire specimen 52 cm long, attached above and below to pulleys so that it can be stressed as desired while keeping the experimental length constant. The time required to reduce the amplitude of the oscillations of the rod to half the original value is measured and the viscosity is then calculated by a simple formula, the derivation of which is explained. Values for a number of metals are given. For most metals the method gave higher values than earlier authors' figures ; an exception was iron, which was about the same, and which also gave almost exactly the same value as that for steel, for which material the earlier authors had found figures only half that for iron. The author concludes that the internal friction in iron and steel is due to the rubbing of particles of similar sizes in the two materials. The damping in iron and steel is influenced slightly by changes of temperature.—A. E. C.

The Non-Destructive Testing of Materials. S. Förster. (Werkstatt und Betrieb, 1948, vol. 81, Mar., pp. 71–74 ; Apr., pp. 103–104). The advantages and disadvantages of X-ray, magnetic, and sonic methods of testing metals are discussed.—R. A. R.

Design of an Ultrasonic Analyzer. (Electronics, 1947, vol. 20, Dec., pp. 102–105 : Electrical Engineering Abstracts, 1948, vol. 51, Apr., p. 89). Metal strip is tested for flaws by passing it through an oil or water bath, intercepting the path of an ultrasonic beam, the attenuation of which is increased about 100 times in the presence of flaws. A noise source is used as ultrasonic generator and working frequencies of 50, 440, 880, or 2000 kc/sec can be selected by tuned circuits. A wide-band amplifier acts as receiver, energizing a relay to operate a lamp, bell, or the like, when a flaw is detected. The transducers used depend on the frequency and a number can be run in parallel for wide strips.

Naval Radiographical Laboratory to Assist Welding and Casting Technique. A. Wilson. (Metallurgia, 1948, vol. 37, Apr., pp. 305–306). Very brief details are given of X-ray equipment and the radiography room at Chatham Dockyard, the building of which was started in the latter part of 1945. A. E. C.

New Creep Testing Machines. J. Marin. (Automotive Industries, 1948, vol. 98, May 15, pp. 46–47, 78 : [Abstract] Metals Review, 1948, vol. 21, June, p. 26). In the past, most creep tests have been made on specimens subjected to simple static tensile stresses. Recently, several static-tension, static-torsion, static-bending, fluctuating-torsion, and fluctuating torsion-tension, creep-testing machines were developed at the Pennsylvania State College.

Creep Tester for Elevated Temperature Work. (Product Engineering, 1948, vol. 19, May, pp. 96–97). A creep-testing machine made by Baldwin Locomotive Works, Philadelphia, is described. It takes specimens 0·505 in in dia × 6¼ in long. Time and strain indications are given by two counters, one of which counts the number of breaks in electrical contacts which are separated by the extensometer at each length increment of 0·00025 in.—R. A. R.

Discussion of a Paper by E. Houdremont and G. Bandel on "The Effect of Titanium on the Creep Strength of Steels." (Iron and Steel Institute, 1948, Translation Series, No. 349). This is a translation of the discussion on the above paper by E. Houdremont and G. Bandel which appeared in Archiv für das Eisenhüttenwesen, 1942, vol. 16, Sept., pp. 85–100. (*See* Translation No. 278).—R. A. R.

High-Temperature Metals. L. N. Rowley. (Power, 1947, vol. 91, Oct., pp. 79–94 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Mar., p. 37). A detailed account is given of recent developments in heat-resistant metals and alloys ; it deals with the behaviour of metals subjected to normal stresses, the influence of temperature on metals, creep, and heat-treatment of heat-resisting metals. A list is given of these metals, manufactured in America, with their compositions and properties. The use of heat-resisting metals for machines operating at high temperatures is described.

Notes on the Behaviour of Steel after Rapid High Frequency Heating. Plaskine, Souborovskaia, and C. K. Boudnikova. (Bulletin de l'Académie des Sciences, U.R.S.S., 1948, No. 1, pp. 131–138).

Materials for High Temperature Piping. (Heating, Piping and Air Conditioning, 1947, vol. 19, June, pp. 90–91 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 3/4, p. 605). The properties of carbon, molybdenum, and chromium–molybdenum steels for service at temperatures of 500–600° C are outlined.

METALLOGRAPHY

Systematic Etching Tests Identify Non-Metallic Inclusions in Steel. H. V. Kinsey. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Apr., pp. 14–16). The systematic scheme of etching analysis recommended in "Metallographers Handbook of Etching" is reproduced.—M. A. V.

100-kV. Electron Microscope. (Engineer, 1948, vol. 185, Apr. 30, pp. 421–422). A description is given of the Metropolitan-Vickers 50-kV electron microscope EM3 which has been developed after three years' experience with the EM2. The microscope itself is mounted on a desk containing the vacuum equipment with the controls on the left and space for writing on the right. The magnification can be varied from 1000 to 100,000 times without changing the holder. Many technical improvements, each contributing towards a reduction in the over-all dimensions, have been incorporated.—R. A. R.

The Microstructure of Tinplate. T. Fielding. (Tin Printer, 1948, vol. 24, No. 278, pp. 8–9 ; No. 279, pp. 8–9).

Laws of Grain Growth of Carbides during Isothermal Tempering. Part I. Grain Growth during Tempering of Carbon Steel. S. Z. Bokshtein. (Journal of Technical Physics, U.S.S.R., 1947, vol. 17, Dec., pp. 1513–1520 [in Russian] : [Abstract] Metals Review, 1948, vol. 21, June, p. 46). By means of static methods of microanalysis a quantitative evaluation of the process of grain growth of the carbide phase in plain carbon steel during isothermal tempering was obtained. This phenomenon consists of the continuous decrease of the number of small carbide particles and formation of large ones. This process is quite intensive during the first stage of tempering, but decreases quite markedly with the time. There are twelve references.

The Quantitative Microstructural Analysis of Alloys. M. E. Blanter. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 414–422). [In Russian]. A method is described by which the phases present in an alloy can be quantitatively estimated from the results of microscopical examinations of polished and suitably etched specimens. Using an eye-piece micrometer, the mean dimensions of each grain (in a randomly chosen field of view) cut by the hairline are measured, and the procedure is repeated until 200–250 measurements have been made. By counting the number of grains visible in fields of known diameter, the number of grains per square millimetre is also determined. From these results, in the form of distribution curves, the volume of 100 "statistical grains" is calculated on the basis of the assumption that the grains are spherical and of the fact that the volume of a slice of a sphere depends, for a given thickness of slice, on the radius of the slice and not on that of the sphere ; and hence, allowing if necessary for differences in density, the percentage by weight of the phase in question can be calculated. This method is compared with some others which have been proposed, and the results obtained by its use for the determination of cementite in a steel are shown to agree closely with those from chemical analysis. The examination of the fields is best accomplished by projecting a positive slide on to metric graph paper, and the most accurate results are obtained when the boundary of a grain is taken to lie midway between its inner and outer contours.

A new method, which has been experimentally confirmed, is also proposed for the determination of the spatial distribution of grains in an alloy from the results of microscopical examination of plane, etched fields. This is based on the assumption that the grains are spherical but, in spite of this, completely fill the space and, that the largest section

found in the plane corresponds to the largest grain in the volume under consideration. An example of the application of this method is given.

The values of some functions frequently used in both the above methods are tabulated.—S. K.

A Method of Isolating Carbide and Non-Metallic Particles of a Steel Specimen in Their Original Distribution. A. Skapski and C. Benedicks. (Arkiv för Kemi, Mineralogi och Geologi, 1947, vol. 23, No. 4/5 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 3/4, p. 503).

Metallographic Structure of Steels. G. Testero and R. Parigi. (Ingegnere, 1946, vol. 20, May, pp. 335–344 [in Italian] : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 1/2, p. 245).

An X-Ray Goniometer for the Study of Preferred Orientation in Polycrystalline Aggregates. W. A. Wooster. (Journal of Scientific Instruments, 1948, vol. 25, Apr., pp. 129–134). An X-Ray goniometer, based on the design originally proposed by Kratky, for the purpose of studying the preferred orientation of cystals in metal sheets or other polycrystalline aggregates is described. The theory of the interpretation of such photographs is given together with two types of charts which, when superimposed on the photographs, enable a pole-figure, based on a stereographic projection to be obtained. The particular virtue of this method is that almost the whole information required for a complete pole-figure may be obtained from one photograph.

CORROSION

The Application of Electrochemical Theory to Corrosion. G. M. Willis. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy, 1946, Part 3, " Corrosion "). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 285.

Corrosion Inhibitors. A. G. Sussex. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy, 1946, Part 3, " Corrosion "). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 540.

Practical Corrosion Tests. S. C. Johnson. (Australian Institute of Metals Symposium on Recent Advances in Physical Metallurgy, 1946, Part 3, " Corrosion "). *See* Journ. I. and S.I., 1948, vol. 159, June, p. 232.

Extract of Linseed Meal as a Corrosion Inhibitor for Iron and Steel. E. I. Gourovitch. (Journal of Applied Chemistry, U.S.S.R., 1946, vol. 19, pp. 140–147). [In Russian].

Relations of Sulphate Reducing Bacteria to Corrosion of Steel in Sea Water. R. L. Starkey and J. D. Schenone. (Journal of Bacteriology, 1947, vol. 54, July, p. 46).

A Study of the Kinetics of Bearing Corrosion and Oil Oxidation : Correlation of Various Test Methods. H. R. Lehman and L. K. Herndon. (Ohio State University, Engineering Experiment Station News, 1948, vol. 20, Feb., pp. 45–52 : [Abstract] Metals Review, 1948, vol. 21, May, p. 14). A method of graphical analysis for the corrosion curves exhibited by the MacCoull Bearing Corrosion Tester is presented, and its application to such widely differing test methods as the Indiana stirring oxidation test and the oxygen-absorption method of Dornte is demonstrated. This indicates the existence of a method of correlating the extensive bearing-corrosion and oil-oxidation data in the literature.

Redox Systems as a Means for Protecting Metals against Corrosive Attack by Water-in-Oil Emulsions. J. Reitstötter. and J. Rzymkowski. (Archiv für Metallkunde, 1948, vol. 2, Jan., pp. 9–12). After giving a short definition of water-in-oil emulsions the authors explain the theoretical relationship between the potential of iron as it rusts and the potentials and *r*H values required by a corrosion inhibitor for iron and other metals. Basic Redox systems with high *r*H values are used to protect the surfaces of metal vessels containing water-in-oil emulsions. Diphenylamine, with an *r*H value of 26–27, has been found a practical inhibitor for this purpose. [The Redox scale is indicated by *r*H, which is the negative logarithm of the existing hydrogen pressure].—R. A. R.

ANALYSIS

Calcium in Steel. C. G. Carlsson. (Metallografiska Institutet : Jernkontorets Annaler, 1948, vol. 132, No. 7, pp. 221–236). [In Swedish]. A spectrochemical method for the determination of calcium in steel, using solutions, is described. To avoid contamination only quartz or platinum vessels were used, and acids and water were redistilled in a quartz apparatus. The solution was evaporated on carbon electrodes, and for the excitation an interrupted D.C. arc was used. By adding 10% of potassium (as K_2CO_3) the sensitivity could be increased ten times, and an amount of 8 mγ of calcium (1 mγ = 10^{-9} g) on the electrode could be quantitatively determined in the presence of 4 mg of iron. By extrapolation 1 part per million could be determined. By dissolving the steel in hydrochloric or nitric acid the calcium that is soluble in acids was determined, and by filtering such a solution the insoluble inclusions in the steel were isolated and analysed after being decomposed by fusion with K_2CO_3. A simple method for determining the total calcium content comprised the addition of hydrofluoric acid after the steel had been dissolved in hydrochloric acid.

Some steel samples, most of them melted in basic furnaces, were analysed for calcium in order to find out if some calcium may be present in steel. A survey of the literature showed that no solubility of calcium in steel has been detected, but the methods of analysis previously used were not very sensitive. In one sample to which a large amount of CaSi had been added, 0·0036% of calcium was found, but in all other samples the calcium content was less than 0·001%, and it was probably present in non-metallic inclusions (insoluble in acids). This calcium had probably got into the steel with the ferro-silicon, which usually contains one or two tenths of 1% of calcium. Magnesium was determined in a few samples at the same time as calcium but only very low values were obtained.

Spectro-Analytical Determination of the Basicity of Open-Hearth Slags. K. A. Shisterman and Z. A. Ustalova. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 500–501). [In Russian]. A method of determining the basicity of open-hearth slags is given in which the specimen, in the form of a special briquette, is exposed to the action of condensed sparks, the calcium and silicon lines being compared. The results obtained are compared with those of chemical analysis. S. K.

Determining Nickel with Dimethylglyoxime. (Metalloberfläche, 1947, vol. 1, Sept., pp. 225–226). The method for preparing an aqueous dimethylglyoxime solution for determining nickel proposed by E. Raithel, and several analytical procedures are described.—R. A. R.

Determination of Nickel by Standardized Dimethylglyoxime Solution. E. I. Grenberg and M. Ya. Genis. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., p. 491). [In Russian]. A brief note is given on the use of dimethylglyoxime solutions for the determination of nickel in nickel–chromium steels, and the effect of copper on the determination is mentioned.—S. K.

Construction of a Semi-Micro Gas Analysis Apparatus. S. G. Demidenko and B. A. Geller. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., p. 501). [In Russian]. An apparatus for the analysis of samples of the order of 1–2 ml is described ; it has special provision for a large area of contact between gas and absorbent.—S. K.

New Method for the Determination of Oxygen in Iron and Steel. N. Vigna. (Helvetica Chimica Acta, 1946, vol. 29, No. 7, pp. 1667–1669 : [Abstract] Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Mar., p. 43). In this method the specimen is heated first to 350° C and then to 1200° C in a current of nitrogen. The oxygen evolved is collected and measured in a burette.

New Equations for the Calculation of Hydrogen and Methane by Their Joint Combustion. S. V. Nikolaev. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., p. 499). [In Russian]. To minimize errors in the calculation of hydrogen and methane from the results of their joint combustion, the following equations are proposed :

$CH_4 = A[a-(b+c)/3]$ and $H_2 = 2A[a-2(b+c)/3]$,

where A is the volume of gas taken for combustion, in which volume a of oxygen is used and which results in a contraction in volume of c and the production of the volume b of carbon dioxide.—S. K.

The Volumetric Determination of Molybdenum in Steels. P. Ya. Yakovlev. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 397–398). [In Russian]. The following method, which has been found satisfactory for the determination of molybdenum even in highly alloyed steels, is given. A 1-g sample of the steel is dissolved in 50 ml of HCl or aqua

regia. If in the former, the solution is oxidized with nitric acid, the excess of which is then removed by twice evaporating to dryness with HCl. The dry salts are dissolved by warming with 10–15 ml of HCl and, after cooling, 50 ml of a 20% solution of stannous chloride and 30–50 ml of a 7% solution of ammonium or potassium thiocyanate are added, and the liquid is then extracted once with 20–25 ml and twice with 10–15 ml of ether in a separating funnel. After separating, the ethereal extract is warmed with 30–40 ml. of water and to the resulting aqueous solution are cautiously added 15 ml of conc sulphuric acid followed by nitric acid till a clear liquid is obtained. This solution is then evaporated till fumes of sulphur trioxide appear, and, if the liquid is not clear, the evaporation is repeated with 5–10 ml of HNO_3. The cooled liquid, diluted to 50 ml with water, is reduced with liquid zinc amalgam and titrated with permanganate under carbon dioxide.—S. K.

Application of the Drop Method for Approximate Quantitative Analysis in the Classification of Alloys. E. I. Nikitina. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 493–497). [In Russian]. Methods of approximate quantitative analysis are considered in which the solution is formed by the action of a single drop of reagent on the surface of an alloy, the solution then being removed and tested by spot, volumetric, or colorimetric technique. After the use of this method for the determination of copper in aluminium alloys and of silicon in silumin has been considered in detail, an example is given of its applicability to the rapid classification of alloy steels. For this purpose 0·02 ml of nitric acid was applied to the surface of the steel and the manganese content of the resulting solution was determined colorimetrically.—S. K.

The Rapid Determination of Silica in Agglomerate. Iu. I. Usatenko and P. A. Bulakhova. (Zavodskaya Laboratoriya, 1948, vol. 14, Apr., pp. 492–493). [In Russian]. The best conditions for the determination of silica in agglomerates, using 0·1% gelatin solution for coagulation, are considered, and a procedure is suggested which reduces by half the time required for this determination.—S. K.

BOOK NOTICES

AMERICAN WELDING SOCIETY. "*The Fracture of Metals*." A Report to the Bureau of Ships, U.S. Navy, by M. Gensamer, E. Saibel, J. T. Ransom, and R. E. Lowrie. 8vo, pp. 84. New York, 1947: American Welding Society. (Price $1.00).

In recent years the failures encountered in welded ships have focused attention on the brittle fracture of metals. The problem of brittle fracture, however, is not confined to welded steel structures, but may also be present, for example, in armour plating and ordnance material. This survey of the present knowledge of the laws and fundamental mechanism of fracture is, therefore, particularly welcome. An extensive bibliography of nearly 300 references is appended, and suggestions for long-term research are made.

The survey, which is in two parts, emphasizes the theoretical and fundamental aspects of the fracture of metals, although a few pages are devoted to the application of basic principles to the notched-bar impact test and ship cracking. The subject is dealt with in terms of flow strength and fracture strength, and a review is made of the effect on these factors of the state of stress, previous strain history, cyclic loading under combined stresses, size effects, temperature, strain rate, composition and metallurgical structure.

In general, most attention has been devoted in the past to the resistance to deformation. Few studies have been made of the resistance to fracture, largely because of the experimental difficulties introduced by the deformation which occurs before fracture. It is suggested that fracture strength may be more important than resistance to flow in controlling the capacity to deform and absorb energy without fracture, and the survey recommends an intensive investigation of this property.

Various theories of fracture are reviewed, pride of place being given to those originally advanced by Griffith and Fürth. The crack theory originally proposed by Griffith, and subsequently modified by several physicists, is based on the energy required to propagate cracking through the metal, while Fürth's theory is founded on an analogy between rupture and melting, *i.e.*, the strain energy required for fracture is equated to the energy required to melt the metal, corrected to the same temperature. While these theories have not been extended to explain the effect of the variables on the fracture strength, it is quite probable that both theories are partly correct and that the two may be integrated into a single theory.

An ambitious experimental programme outlines a series of co-ordinated studies based on concepts of flow stress and fracture stress. It is rightly pointed out, however, that before the information obtained from these researches can be applied it will be necessary to acquire a much better understanding of the factors operating under practical conditions. It is suggested that a concurrent investigation of the effect of each variable on the brittle temperature of impact testing would enable the results of the Charpy test to be correlated with the suitability of the material for specific uses.—T. DENNISON.

HILTON, B. R. "*Engineering Machine Shop Practice*." Second Edition, 8vo, pp. x + 189. Illustrated. London, 1946. Sir Isaac Pitman and Sons, Ltd. (Price 6*s*.).

This book deals capably with the basic machine-shop operations, marking out, the use of hand tools such as hacksaws, chisels, files, scrapers, taps, and dies; its treatment of the use and applications of the power drill, the centre-lathe, the shaper, and the miller are adequate for the student and apprentice for whom it is intended. However, the author's section on the materials of engineering construction is, metallurgically, inadequate, and at points misleading; it is also rather unfortunate that a book published so recently should contain no mention either of hard-metal tools or of the extensive development of form grinding as a machine-shop operation.—J. P. S.

HOLLOMON, J. H. and L. D. JAFFE. "*Ferrous Metallurgical Design*." 8vo, pp. x + 346. Illustrated. New York, 1947: John Wiley and Sons, Inc.: London: Chapman and Hall, Ltd. (Price 30*s*.).

The authors' main purpose in writing this book was to describe and explain a procedure that they have developed for use in designing highly stressed steel components so that when made of a suitable steel, properly heat-treated, they will have the required properties and may be depended upon to give satisfactory service. The authors make the assumption, with which most metallurgists will agree, that the steel must be heat-treated in such a way as to produce a tempered martensitic structure. They maintain that unless the designer understands how this structure is produced, and has an understanding of the mechanical behaviour of steel in general, and of steel having a tempered martensitic structure in particular, he is not in a position to tackle successfully the engineering problems involved in the design.

In the first three chapters, the authors set out to provide the necessary fundamental information. Most of this is well done, but in parts the going seems unnecessarily heavy.

The authors then turn to more practical aspects, and provide a wealth of information regarding mechanical properties and mechanical testing (Chapter 4), quenching media and their effects on parts of various shapes and dimensions (Chapter 5), hardenability as affected by chemical composition and grain size (Chapter 6), quench cracking as affected by the shape and composition of the component and by the quenching practice (Chapter 7), and finally the effects produced by tempering straight carbon and alloy steels at various temperatures and for various times (Chapter 8). The numerous tables and graphs that these chapters contain constitute an invaluable collection of metallurgical and engineering data pertinent to the problem of the design of highly stressed steel parts.

In the two concluding chapters, the authors' recommended procedure for applying the fundamental knowledge and the practical data to the problem of producing an efficient design, is described and illustrated by means of examples.

For the most part, the book is written in clear and simple language, but at times the authors have made the mistake of assuming that expressions well-known to specialists in

certain branches of physical metallurgy are either self-explanatory or familiar enough to need only the briefest of definitions. The result is that unless the reader is already well versed in recent literature on the subjects covered by the book, he will find some parts of it very difficult even to the point of unintelligibility. For instance, if an enlightened reader particularly interested in quench-cracking turned to the chapter on that subject without first mastering the earlier chapters, he would find himself expected to be familiar with "flow-stress" and "fracture-stress" curves and with the expression "HD product." The first of many references to this product in Chapter 7 comes in the seventh paragraph, and this may be quoted as an illustration of the difficulties that the reader has to overcome:

> "The temperature differences within the part are greater the higher is the HD product (Chapter 3). An estimate of the variation of surface and center stresses in a quenched cylinder with temperature difference and with HD is shown, for a hypothetical steel, in Fig. 110. It will be noted that, as the temperature difference (HD product) increases from zero, the tensional stress at the surface increases."

The final sentence in the passage quoted implies that "temperature difference" and "HD product" are synonymous, whereas the preceding sentence implies that they are different factors. The first sentence implies that the meaning of "HD product" is explained in Chapter 3. Actually, this chapter deals with "Mechanical Behaviour" and contains no reference to the product in question. The definition of "HD product" is tucked away near the end of Chapter 2, eight pages after the expression first appears in the caption of a figure which is unintelligible unless the meaning of the expression is understood.

It is unfortunate that the authors have not taken more care to be helpful, but even though the average reader may have to skip the more difficult sections, he will still find a great deal in the book to interest him and to add to his knowledge and understanding of the behaviour of steel.—M. S. Fisher.

Mahin, E. G. "*Elementary Physical Metallurgy.*" 8vo, pp. xii + 276. Illustrated, Brooklyn, N.Y., 1948: Chemical Publishing Co., Inc. (Price $6.00).

The title is misleading, because the book deals only with certain aspects of physcial metallurgy and, in the author's words, "does lean rather heavily towards the ferrous side of the subject." It is true that "the principles which are fundamental to the physical metallurgy of the iron-carbon alloys are fundamental also to all physical metallurgy," but, in a book that is intended to serve as an introduction to this branch of metallurgy, mainly for students of metallurgy but also for engineers, one would expect to find some reference to such alloys as brasses, bronzes, and bearing metals and to such subjects as dendritic crystallization, corrosion, and scaling, all of which are ignored.

The book is very readable and nicely illustrated, and some parts of the subject are really well covered. The chapters on mechanical properties and on the surface-hardening of steel, for example, are if anything, unnecessarily good. There is, however, a regrettable lack of balance in the author's treatment of the subject. For instance, the chapters on "Metallography" and "Mechanical Deformation" occupy only 32 pages altogether, which is just one page more than is devoted to the relatively unimportant subject of surface-hardening.

The book contains a good deal of useful, reliable and up-to-date information, and is worth borrowing from the library for an evening or two, but as an introductory text-book, whether for metallurgists or engineers, it cannot be recommended.—M. S. Fisher.

Verein Deutscher Eisenhüttenleute. "*Aus der Fachsprache des Eisenhüttenmannes.*" Bearbeitet vom Verein Deutscher Eisenhüttenleute. 2., erweiterte Auflage. Deutsch–Englisch. Englisch–Deutsch. Sm. 8vo, pp. 106. Düsseldorf, 1948: Verlag Stahleisen m.b.H.

This technical vocabulary is necessarily limited in scope by its small size, and is therefore confined to terminology in common use in iron and steel manufacture. Nevertheless, on the basis of a few random tests, it appears that the compilers have continued to make it remarkably complete, and even to include some technical terms not to be found in larger dictionaries. It is necessary for the user to have some knowledge of the German language to avoid being mislead when a word has several meanings; thus for example, six German equivalents are given to the English word "set." With this reservation, this compact little dictionary, which is well produced and legibly printed, can be confidently recommended to the English reader of German iron and steel technical literature.—M. A. V.

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Verein Deutscher Eisenhüttenleute. "*Aus der Fachsprache des Eisenhüttenmannes.*" Bearbeitet vom Verein Deutscher Eisenhüttenleute. 2., erweiterte Auflage. Deutsch–Englisch, Englisch–Deutsch. Sm 8vo, pp. 106. Düsseldorf, 1948: Verlag Stahleisen m.b.H.